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Guidelines for Community Noise Impact Assessment and Mitigation

Final Report

of the

I-INCE Technical Study Group on Community Noise: Environmental Noise Impact Assessment and Mitigation (TSG 6)

Prepared by the Members and Consultants of TSG 6

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GUIDELINES FOR COMMUNITY NOISE IMPACT ASSESSMENT AND MITIGATION

Foreword

This report was prepared under the auspices of, and as a public service by, the International Institute of Noise Control Engineering (I-INCE) for consideration by appropriate international and national authorities. I-INCE is a non-governmental federation of professional societies from countries around the world. I-INCE is dedicated to advancing the engineering control of noise and vibration. Operational policies and procedures of I-INCE are established by a Board of Directors and approved by a General Assembly. The General Assembly consists of representatives of the member professional societies and the Board of Directors. The Board of Directors and the General Assembly meet at least once a year during annual Congresses sponsored by I-INCE on noise control engineering.

This report was approved by the I-INCE member societies in January 2011 followed by the recommendation of the I-INCE General Assembly at its meeting in 2010 June 13.

BACKGROUND

A proposal to form a reformulated I-INCE Technical Study Group (TSG) was made to the I-INCE Board of Directors during INTER-NOISE 2001 in Den Haag, the Netherlands. This proposal was followed by another discussion with the I-INCE Board of Directors at INTER-NOISE 2002 in Dearborn, Michigan, USA. A proposed scope (as listed below) was presented to and accepted by the I-INCE Board of Directors in 2002 October for the formation of TSG 6, Community Noise: Environmental Noise Impact Assessment and Mitigation. Member Societies of I-INCE were then requested to appoint experts to be members of TSG 6.

The scope of TSG 6 (as established by the I-INCE Board) was as follows:
The objective for this working group is to provide practical guidance to policy makers who are involved with regulation and control of community exposure to environmental noise, excluding the noise generated by residential neighbors, through the use of an environmental impact assessment process. The Final Report of I-INCE TSG 6 will focus on performing an environmental impact analysis, but will also provide information on the use of dose-response relationships and land use planning to achieve the goal of effective control of exposure to environmental noise. The report will be aimed primarily at a non-technical audience. It will advocate a flexible approach to control of exposure to environmental noise in a community through informed choices for the estimated costs of achieving various degrees of noise control versus the benefits of mitigating exposure to environmental noise. The report will also indicate areas that need further research and international harmonization.

The emphasis of the report will be on how a well-conceived environmental impact analysis process (EIAP) can be an integral part of an effective strategy for control of environmental noise, with land use planning as an essential element of the strategy, especially for countries that are still experiencing substantial community development.

The report from will also address the issues of how noise control policies may have to account for national and global regional differences in cultures and expectations, differences in national perceptions of the appropriate role of government, differences in the availability of financing and technical support for effective noise control, and differences in the willingness of populations to accept a long-term commitment to implement the required regulations and noise control measures.

Primary subject classification: 08; Secondary subject classification: 80

TSG 6 Members and Consultants

Each member of TSG 6 was appointed by a Member Society of I-INCE. In addition, a group of international Consultants provides their insights and comments in the development of the TSG 6 report. The following lists the membership of TSG 6.

Convener: Lawrence Finegold (USA)

Member	**I-INCE Member Society**
Stephen Samuels	Australian Acoustical Society
Werner Talasch	Österreichischer Arbeitsring für Lärmbekämpfung
Jean-Pierre Clairbois	Belgian Acoustical Association
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Hideki Tachibana	Acoustical Society of Japan and INCE/Japan
Soogab Lee	Korean Society for Noise and Vibration Engineering
Ronny Klæboe	Norwegian Acoustical Society
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Consultants: Bernard Berry, Marion Burgess, Philip Dickinson, Michiko So Finegold, Ian Flindell, Truls Gjestland, Andrew Hede, Stephen Keith, Selma Kurra, John Ollerhead, Paul Schomer, Michel Vallet, Martin van den Berg

The formal I-INCE Member Society TSG 6 members and the identified consultants provided a wealth of advice and inputs in the development of the TSG 6 Final Report. In addition, several individuals provided additional inputs which are to be acknowledged, including those from Nicole D. Porter, Marion Burgess, and Lawrence S. Finegold, in additional to the previous work by these people, plus the original work of John Ollerhead and Ian Flindell. This report represents a consensus of the members of TSG 6.

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Guidelines for Community Noise Impact Assessment and Mitigation[1]

1. Introduction: Objective and Background of I-INCE TSG 6

The objective for this I-INCE Technical Study Group is to provide practical advice on noise management strategies for those involved with the regulation and control of community noise. This report provides guidance on performing an environmental noise impact analysis. In particular, it outlines a general process that is recommended to balance the positive effects of controlling exposure to community noise against the costs and technical feasibility of achieving effective noise control. The concepts presented in this report complement those being implemented worldwide. This Final Report of TSG 6 should be viewed as supplementing existing and still evolving community noise policies.

The primary objective for this international study group is to provide practical guidance to those involved with regulation and control of community exposure to environmental noise, excluding the noise generated by neighbors. This report focuses on providing guidelines and outlining the steps to be followed when performing an environmental impact analysis. It advocates a flexible approach to the control of exposure to environmental noise in a community through informed choices involving consideration of available alternatives and the expected effects of exposure to community noise. With this approach, a well-conceived environmental impact analysis process (EIAP) can be an integral part of an effective strategy for control of environmental noise.

This report from TSG 6 takes a worldwide approach to strategies for managing exposure to community noise from the immission perspective; i.e. noise that is received by residents surrounding the proposed development project. Current management policies were studied and, and a result, the guidelines provided in this report aim to provide a method for assessing community noise impact with a view to achieving the desired outcomes.

Section 2 of this report discusses the need for guidelines on community noise impact assessment. This is followed in Section 3, with an identification of the issues to be considered in practical community noise impact assessment. Section 4 provides guidelines for performing a community noise impact assessment. Section 5 gives some case examples showing how the guidelines can be applied. The Appendices provide additional background information on noise exposure-response functions and exposure benchmarks.

The overall purpose of the TSG 6 report is not to be an advocate for either community developers or for community residents. When new developments are considered in any community, such as an expansion to a local airport, a new highway or a new industry, there are both benefits and costs which must be considered for all of the relevant involved parties. The crucial issue is how to best make the tradeoffs between the economic benefits to both the community and the developers for a proposed community development project versus the

[1] Although the TSG 6 Final Report uses the phrase noise "Mitigation", and this is included in the formal I-INCE title for this TSG, the goal of noise management techniques such as Environmental Impact Assessment is really to provide adequate protection of the public health, which is similar, but not exactly the same as the usual understanding on "mitigation" as "minimizing any negative effects of exposure to community noise". The word "remediation" is also acceptable as an alternative to the word "mitigation", but the goal is always to make sure that the public health is adequately protected by minimizing any significant negative impacts from new community development projects.

negative impacts to the community in terms of the effects of the expected increases in community noise levels, such as community annoyance, sleep disturbance, health effects, etc. The environmental impact assessment process is, thus, a methodology to provide an analytical process for the negotiations necessary between developers and the affected community, in conformance with general guidance provided by the government and with the government being an arbiter between the involved stakeholders to make sure that community development is sustainable and has minimal impact on community residents.

2. Rationale: Why Do We Need Guidelines on Environmental Noise Impact Assessment and Mitigation?

Current estimates suggest that many millions of people around the world are seriously affected by (environmental) noise in their communities. This noise is increasingly perceived as being related to the sustainability of growth because it has negative effects on the quality of life and well-being of people around the world and because of its potential for causing harmful physiological health effects. With increasingly urbanized societies it is inevitable that unless control of noise impact is adequately dealt with, this situation will only get worse.

Deciding on the most effective noise management option in a specific situation is not just a matter of defining noise control actions to achieve the lowest noise levels or meeting arbitrarily chosen criteria for exposure to noise. The goal should be to achieve the best available compromise between the benefits to society of reduced exposure to community noise versus the costs and technical feasibility of achieving the desired exposure levels. On the one hand there are the rights of the community to enjoy an acceptably quiet and healthy environment. On the other are the needs of the society for a new or upgraded facilities, industries, roads, recreation opportunities, etc., all of which typically produce more community noise. Each community may well establish its own acceptability criteria which (hopefully) are based on sound scientific assessment. If the proposed development or upgrade of an existing facility is likely to produce noise, the first step in any impact assessment process is to define the extent of the potential noise impacts. It is when these impacts exceed the applicable exposure criteria that an environmental noise impact assessment and mitigation process[1] should be undertaken. This report provides guidelines, based on international experience, on the steps that should be followed to undertake this assessment process in a rigorous manner.

3. Background: An Introduction to the Issues to be Considered in Practical Noise Impact Assessment.

The aim of an Environmental Impact Assessment (EIA) is to provide environmental protection by foreseeing environmental problems and avoiding them. It is widely used as an aid to decision making for many forms of development. Its strength is to enable the best environmental balance to be found between a project and its surroundings and in helping to determine whether the development is acceptable. Many countries around the world, including most industrialized nations, have either regulations or guidelines describing how to perform environmental noise impact assessments. In addition to national approaches (see References [1-5] for examples), there are also regulations from international agencies such as the European Commission [6] and guidelines from organizations such as the United Nations

Economic Commission for Europe (UNECE) [7] and the United National Environmental Program (UNEP) [8]. In addition, several conference presentations addressed issues that need to be addressed in developing guidelines for performing environmental noise impact assessments [9-12] and the previous progress of TSG 6 [13-14].

The aim of the current guideline on community noise impact assessment is to set out recommendations for good practice procedures for use in community noise impact assessment of proposed community development projects. The procedure is applicable to both large and smaller proposals. It aims to promote greater consistency and transparency between assessments. As this is a worldwide document, this report recommends the basic framework to carry out such an assessment. By way of a background introduction to the recommended framework, this section sets out some of the key issues that need to be addressed.

3.1 Selecting the appropriate noise level criteria

Sound is a natural phenomenon that only becomes noise when it has some undesirable effect on people or animals. Unlike chemical pollution, noise energy does not accumulate either in the body or in the environment but it can have both short-term and long-term adverse effects on people. These can include annoyance, sleep disturbance, interference with speech and other daily activities, effects on the cardiovascular system and other related physiological health effects, etc. Often, annoyance is the major consideration because it reflects the community's dislike of noise and their concerns about the full range of potential negative effects.

So why does community noise cause annoyance? There are many possible reasons for noise annoyance in different situations. Noise can interfere with speech communication or other desired activities, Noise can contribute to sleep disturbance, which can obviously be very annoying and has the potential to lead to long-term health effects. Sometimes noise is just perceived as being inappropriate in a particular setting without there being any objectively measurable effect at all. In this respect, the context in which sound becomes noise can be more important than the sound level itself.

Different individuals have different sensitivities to different types of noise and this reflects differences in expectations and attitudes more than it reflects any differences in underlying auditory physiology. A noise level that is perceived as reasonable by one person in one context (for example in their kitchen when preparing a meal) may be considered completely unacceptable by that same person in another context (for example in their bed room when they are trying to sleep). In this case the annoyance relates, in part, to the intrusion from the noise. Similarly a noise level, which is considered to be completely unacceptable by one person, may be of little consequence to another even if they are in essentially the same room. In this case the annoyance depends almost entirely on the personal preferences, lifestyles and attitudes of the listeners concerned.

It is against this background that many researchers have attempted to find some basis for establishing sound level criteria above which noise is deemed to be unacceptable and below which it is deemed to be acceptable. Unfortunately, acceptability is itself a relative concept. Most people would agree that, in general terms at least, more noise is bad and less noise is good but there is no fixed level at which noise suddenly switches from acceptable to unacceptable and vice versa.

Various attempts have been made to assess the effect (measured by average reported annoyance, sleep disturbance or a similar type of effect) from community noise (measured by long term average sound levels) and to develop exposure-response relationships. As individual reactions to noise are so varied, these studies need large sample sizes to obtain reasonable correlation between the noise exposure and the response. Any dose-response relationship determined from large studies over a range of communities and cultures will not necessarily represent the reaction of individuals or small communities. These exposure-response relationships are of value for macro-scale strategic assessment purposes where individual differences are not important. Appendix A provides a brief discussion of the current state-of-knowledge concerning the effects of exposure of community residents to transportation noise, the major source of environmental noise in communities.

A noise exposure criterion can be defined as a level of exposure above which a “significant” impact is predicted, although there is no accepted definition of “significant”. A level of significant impact, which must be avoided or mitigated, is essentially a political question determined by politicians. From the scientific perspective, a noise exposure criterion is a choice of one point on a general exposure-response relationship curve. Each country can adopt its own criteria for various noise effects, or use international recommendations, such as those provided by the World Health Organization (WHO) [15]. It is important that when a community noise impact assessment is conducted, the criteria used are valid, defendable and traceable. An example of recommended noise exposure criteria is provided in Appendix B.

Noise level goals and area specific exposure criteria both have an important role in providing guidance to the authorities for assessment of noise impact from a proposal. However it is important that the variability in the reaction of the community is acknowledged and flexibility in the application of such criteria be considered in the impact assessment. It should not be a totally bureaucratic approach where the assessment of the predicted noise impacts is simply a comparison between the predicted noise levels and defined exposure criteria. The process of the noise impact assessment should aim to achieve the best outcome for all those involved, with inputs from all stakeholders and advisors, including representatives of the government, the affected public, development businesses and agencies, and the scientific community. Further information on and examples of noise exposure-response relationships and noise exposure benchmarks are summarized in Appendix A and Appendix B of this report.

3.2 Understanding the relationship between noise emission and immission criteria

Noise emission is the term used to describe the output sound from a source. Within a facility, it is the noise from the individual sources that are operational. For community noise, it is the cumulative noise that comes from that facility. So for a factory it would be the noise levels around the boundary as the factory would be considered as one source that is the sum of all the individual sources within the facility. Similarly for a new road system the noise emission would be the total noise at the edge of the road reservation/boundary from the all the lanes and all the vehicles using that road.

Noise immission is the term used to describe the sound at a point, i.e. at a receiver location. This is the relevant term when considering noise impact on a community as it is the noise that is being received by the people in that community. It is the noise immission being received by the community that is the factor for comparison with the applicable criteria.

If the community areas are adjacent to the boundary of the facility then effectively the noise emission and noise immission are essentially the same. But if the community is some distance from the facility it is the noise immission at that community which is the important factor for assessment. The amount by which this noise immission is in excess of whatever is considered to the appropriate criterion is the goal for noise mitigation (i.e., preservation of the public health).

3.3 Importance of land use planning

Land use planning is a valuable tool to minimize the potential for excess noise immission. To minimize the potential for excess noise impact it is wise to plan the land uses to avoid as much as possible placing noise sensitive areas near to noise producing land uses. A simple example is to try to consolidate major transportation and locate it away from noise sensitive areas like residential areas, and particular noise sensitive uses like schools. Similarly, when locating areas for new industrial estates, there should be buffer zones between these land uses and residential areas. Commercial areas are less noise sensitive and can be located in these buffer zones.

3.4 Community Involvement

A key feature of any successful assessment is to have the potentially affected community involved in the process. A decision has to be made on the best strategy to adopt to achieve this involvement. Options range from including all the community by holding meetings to which all are invited through to dealing with a small committee representing the community. Giving all the community the opportunity to participate has the obvious advantage of being inclusive but achieving a consensus may be difficult. Use of smaller regional meetings plus the opportunity to contribute such as via web based discussion groups can assist. Selecting a small group as representatives of the community may well make achieving consensus easier. But it is essential that this small group is selected in a fair and representative manner in order for any outcome to be accepted by the community as a whole.

4. Guidelines for Effective Community Noise Impact Assessment

4.1 Overview of Approach

An approach to an effective community noise impact assessment is set out in a six-stage process as shown in Figure 1, below. Following this staged approach is the ideal goal of an assessment, but in practice the steps may merge depending on the nature of the project – as indicated with the feedback arrows. A description of each step is given in this section and Section 5 has case study examples showing the implementation of the process.

4.2 Step 1: Define project requirements and noise problem; gather technical support information

This stage involves work by the proponent and their consultants, and the authority ultimately responsible for approving the proposal. Essentially it requires understanding the problem; what parts of the proposal itself could produce noise, what collateral developments could produce noise and where are the key receptors. During this stage, it is necessary to clearly define the current and future land uses in the vicinity of the proposal. Factors that should also be considered include the potential sources of noise during construction and operation, the level and character of the noise to be generated, those receptors to be considered in the vicinity of the new noise source, the length of time over which the impact will occur; and the time of day, night, week, season or year when the impact will occur.

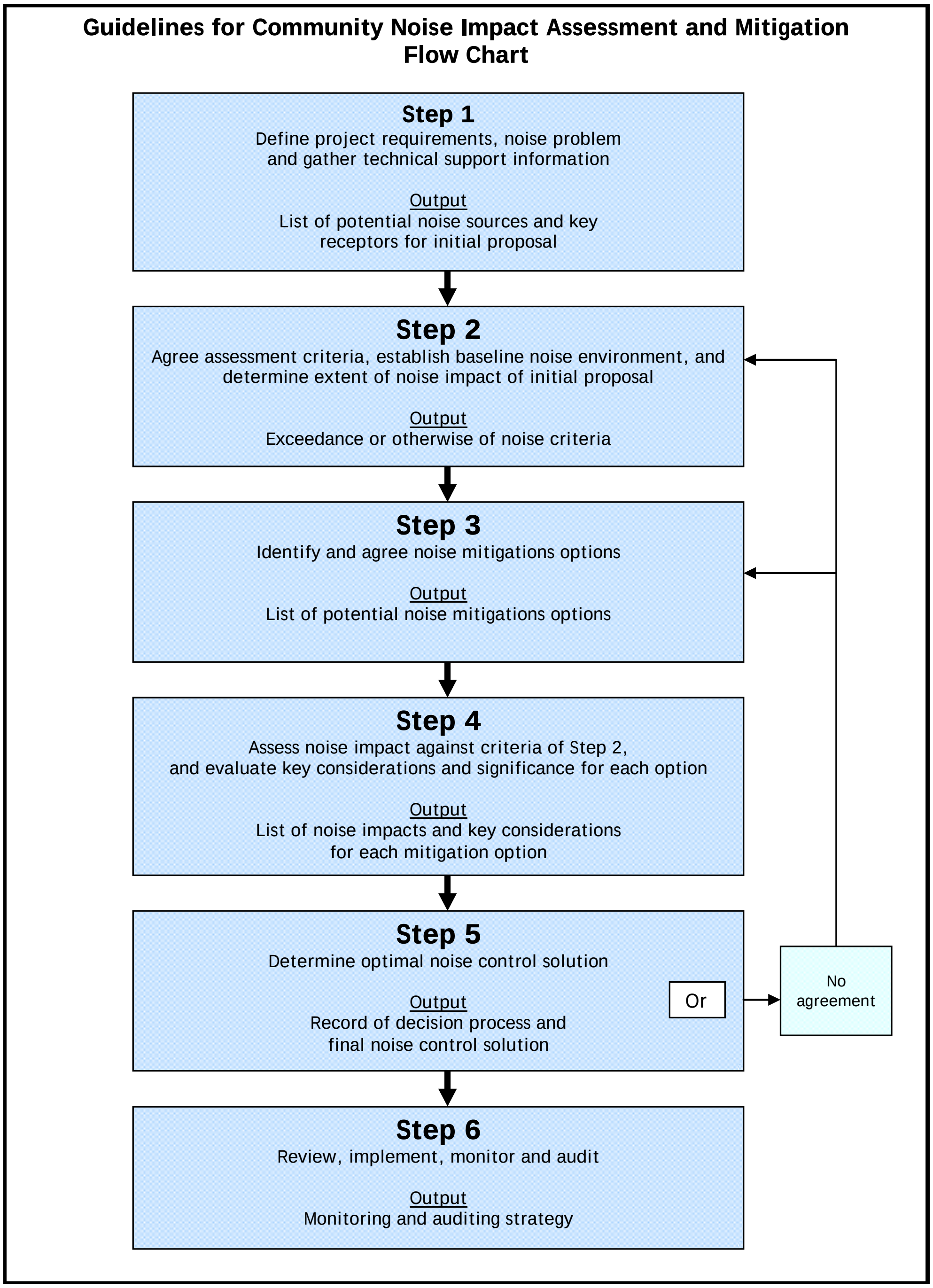

Figure 1—Flow chart showing approach to noise impact assessment and mitigation

Step 1 is a fundamental stage of the process and requires a comprehensive understanding of the project. The proponent will know what they need to construct and how it is proposed to be operated to achieve the project goal. Undoubtedly the initial plans will be optimized from their viewpoint. However, they may have little understanding of, and so given little consideration to, the potential community noise impacts. It is important that someone with an understanding of these potential adverse noise effects be involved at this first stage of the impact assessment. At this stage it is not essential to have clearly defined noise criteria that must be met – the approach should be to minimize, within the constraints of the proposal, the noise impact from the proposal. This should then minimize from the outset the requirements for noise control and mitigation (i.e., preservation of the public health) that may be required to meet the limits set by the authority and the community.

Control of environmental impacts at the planning stage is a very powerful tool. A small change in the layout or design of the proposal can avoid or minimize a noise impact that may otherwise need substantial and often additional costly retrospective measures for noise mitigation. The acoustics consultant should also look outside the immediate area of the site of the proposal to identify those areas in the community which are more sensitive to noise and will require special consideration, such as schools, hospitals etc. Interaction with the other environmental consultants is vital at this planning stage. Selection of the most appropriate options may require consideration of the other environmental effects.

Early in the planning stage the proponent may have limited information on the various elements of the proposal. The acoustics consultant can work with the proponent to minimize the noise at the source by suggesting low noise alternatives. Once the proponent has decided on the plant or equipment etc the consultant will need to do some preliminary predictions of the potential for noise impact for the surrounding communities.

Some examples of recommendations at the planning stage for reducing the noise impact are:

- Relocating a conveyor in a refinery to the shielded side of a building. This may increase its length but could substantially reduce the noise for the community and a need for the proponent from having to enclose the drive mechanism.
- Changing the alignment of a new dedicated busway so that it remains within the reservation for an existing road. This may require some additional engineering works but could save expensive noise walls. For those communities near the existing road there would be little additional noise impact from the buses
- Consolidating as much as possible the elements on the site which are likely to be noise producing to avoid distributing the noise all around the boundary.

The collateral noise that the project could introduce to the community also needs to be identified at this planning stage. This includes additional traffic noise from increased number of cars and trucks on the surrounding roads. Other factors that could follow may not be specifically related to the project. These may include an upgrading of the local service and shopping areas once the project is in operation. The overall community impact assessment may identify this as a potential beneficial outcome but it is important that any consequential noise impact of such developments also be considered.

4.2.1 Output from Step 1

The output from this step is an agreement of the details for the initial proposal for the project, with a list of potential noise sources and main receptors.

4.3 Step 2: Agree on assessment criteria, establish baseline noise environment, and determine extent of noise impact of initial proposal

At the completion of Step 1, the proponent and consultants should have a clear understanding of the potential for noise impacts in the community. The next step is to obtain the perspectives of all the major stakeholders. These include the proponent, the authority that ultimately can approve the project and representatives from community. It is at this point that the applicable community noise goals are defined.

4.3.1 Agree on assessment criteria

The Authority may have specific guidelines or criteria in environmental or community noise policy or regulations. It is important to know at this stage if these are defined limits or if there is scope for variation based on the views of the community. This variation could be in either direction i.e. making the limits less or more stringent.

Criteria can be based on findings from acceptability studies, as discussed in Section 2. These criteria vary for different land use areas and allowance must be made for transition areas between zones with different uses, such as a commercial area near a residential area. They can also vary for different times, with more stringent levels applicable at night due to concerns about intrusion for recreation time and for sleep disturbance. Options for such criteria include:

- Different criteria for the average over specific time periods during the 24 hours i.e. daytime, evening and nighttime;
- Average over a relevant time period for the adjacent land uses, i.e. during the school day or the office hours;
- Level that must not be exceeded during any one hour, or shorter time if applicable, for critical spaces such as hospitals;
- One value which is the average of the A-weighted sound levels during the day and the night but with an adjustment of 10 dB added to the sound levels that occur during nighttime hours, i.e., day-night average sound level (DNL) as used in the US;
- One value which is the average of the A-weighted sound levels during the day, the evening, and the night but with an adjustment of 5 dB and 10 dB respectively for the sound levels occurring during evening and the nighttime hours, i.e., day-evening-night average sound level (DENL) as used in the EU directive on noise.

Another approach is to establish criteria based on background noise levels either in that area or in comparable land use areas. The concept of assessment by comparison with background noise level is easy for the community to understand but there are some disadvantages. Background noise levels vary from day to day so long term noise monitoring is required to obtain a consistent value. Limits for the total noise must be established to avoid gradually increasing or ‘creeping’ background noise as each new source is introduced.

When there is no policy for community noise criteria the authority must, in consultation with the community establish acceptable noise limits. Even when the authority has clear guidelines on limits, it is important that the community be consulted to ensure that these are acceptable to them.

4.3.2 Establish baseline noise environment

Baseline noise refers to the noise environment in an area that may be affected by the proposed development. Baseline noise levels can serve several purposes in the assessment process. They provide information on the current noise climate that may form the basis or justification for the applicable criteria.

The potential for impact from a proposed development is related to the noise the proposal will cause at a given location. Thus, if the distance over which noise from the proposed development could have an impact can be determined, then the boundaries of the area for study can be defined. The receptors within this boundary need to be considered in the baseline survey and these may include uses other than dwellings and animals other than humans. Normally, the objective is to identify those locations most sensitive to or likely to be adversely affected by the proposed development. Also it is necessary to consider whether future noise-sensitive premises, which may be closer to the site than existing receptors, will come into use during the construction and/or operating phases of the proposed development. Furthermore, there may also be circumstances in which local concerns focus on a different receptor position. In those cases it may be prudent to extend the scale of the survey to include such locations. The baseline survey must give time relevant information e.g. time of year, times and days of week.

4.3.3 Determine extent of noise impact of initial proposal

Once the area of potential concern has been established, the consultant's role is to predict the noise impact from the proposal at that stage. Quantifying the noise output, especially at such an early stage in the project, is not a simple matter. Commercial software is available to assist with such prediction. However, it should be noted that, although computer programs have severe limitations in predicting actual levels, they are excellent for comparing one scenario with another, all other things being equal. It is also important to note that all the stakeholders need to understand the limitations of any noise level predictions, particularly at this stage of the project.

A comparison between these estimated noise levels and the goals for noise limits provides an indication of the areas where there is potential for excess noise impact. This must be done using noise indices specified in the criteria selected for assessment. In addition to noise levels, other factors should be considered; including the time period, nature of noise source (intermittency etc), frequency of occurrence, spectral characteristics.

Once these areas have been identified the consultant can work back to the proposal and establish if/where noise mitigation is required.

4.3.4 Output from Step 2

Following Step 2, the baseline levels, predicted levels and selected criteria should enable a breakdown of where there is an exceedance or otherwise of applicable noise criteria.

4.4 Step 3: Identify and agree on noise mitigations options (B, C, D, etc.)

While there may be many parts of the project that produces noise, the key parts that are likely to cause excessive community noise impact have been identified in Steps 1 and 2. It is now time to look at these in detail and develop options for noise mitigation.

At this time the details, including specifications, for the various items of plant need to be carefully examined. It is only from a thorough understanding of the source that options for noise mitigation can be developed. This stage may require 'brain-storming' ideas on potential noise management solutions, each of which should then be evaluated or assessed against the appropriate information and against considerations of what is reasonable and feasible for implementation.

The general strategy for noise control should be considered;

- Reduction of noise at the source – this may have been considered in the preliminary discussions but needs to be reconsidered at this step. The proponent may now agree to a low noise replacement if that would overcome the noise impact. There may be scope to include more stringent limits in noise emission in the specifications for that item. Restricting times of operation can also be considered.
- Reduction of noise between the source and the receiver – this could include relocation so that shielding from buildings and other structures reduces the noise impact. It could also involve construction of purpose built barriers around the source or on the site boundary. Also to be considered is locating site access roads and entrances away from residential areas.
- Reduction of the noise at the receiver – this could involve proposals to construct barriers around parts of the community. It could also involve providing additional noise reduction in the walls and roof of those buildings exposed to excessive noise impact. This approach has been implemented around major airports and road systems. It can provide good noise reduction but only when the person is inside the building.

The whole process should initially be carried out with the proponent and acoustics consultant, and then explored with all the stakeholders.

4.4.1 Output

At the end of the step, there should be a list of potential noise mitigation options.

4.5 Step 4: Assess noise impact against criteria of Step 2, and evaluate key considerations and significance for each mitigation option

Once the options for noise mitigation have been established, the proponent can produce a document with a table that summarizes the options (giving Option A as the initial proposal with no mitigation), demonstrates whether or not the agreed criteria/benchmarks are met, and comments on which are technically feasible, practical, and determine any cost implications.

The document should be clear and honest about the potential noise impact and the options for mitigation as it will become the basis for negotiation. It should also be as quantitative as possible so there is a solid basis for such negotiation. Relative assessments like ‘severe’, ‘major’, ‘minor’ should be avoided as they can be misleading.

Furthermore, having undertaken an assessment for the various noise locations, consideration has to be given to a judgment regarding the possible significance of the overall impact of the proposal with a specific mitigation measures in place.

It is at this point that the consultation with the stakeholders is resumed. The assessment documentation should be distributed to all the stakeholders to allow time for their consideration. The authority may well have the expertise to assess the technical information and it should assist the community understanding and, where necessary, provide additional background briefings.

The ideal outcome is that the proponent agrees to implement a noise control strategy that meets all the goals for noise limits that have been established by the authority and agreed to by the community.

4.5.1 Output from Step 4: A tabulated list of noise impacts and key considerations for each mitigation option

4.6 Step 5: Determine optimal noise control solution

The final recommendation of any assessment procedure should include a written description of the precise basis under which that assessment procedure has been carried out. Earlier steps should lead to a structured evaluation of a number of noise management alternatives. The final step is to rank order the available noise management alternatives while ensuring that all relevant social, economic and contextual factors are properly taken into account. It should be accepted that the most effective acoustical solution may not be the best compromise solution overall. In addition, it is quite likely that persons engaged in carrying out the acoustic assessment may not be competent to assess all the other relevant factors associated with the mitigation options If this is the case then this should be made clear to the other members of the assessment team.

Considerable documentation may be necessary to provide an audit trail which can support any later reviews of decisions made, particularly where circumstances or contexts may change. Where it is possible to follow established or standardized procedures the basis of assessment is already defined and much of the documentation necessary under a more flexible approach might be saved. However, no established procedure can realistically expect to be able to cope with all possible situations that may present themselves. An element of informed flexibility is justified to avoid making irrational decisions. In essence, this is no different from any other form of management where if everyone always followed exactly the same procedures there would be no innovation or competition in the marketplace. Flexibility need not lead to inconsistency provided that where any assessment has departed from established or standardized procedures, then this must be clearly stated in such a way that challenges could be raised if agreement on the best compromise solution cannot be reached.

4.6.1 Output from Step 5

A record of the decision process and any agreed-upon final nose mitigation approaches are to be documented.

4.7 Step 6: Review, implement, monitor and audit

The proposal (as amended by the agreed mitigation options) needs to be implemented following a review of the assumptions, measurements and calculations leading to the final design. Documented records should be kept and be independently audited by the enforcement authority which can also carry out spot checks. Such procedures can demonstrate compliance (or otherwise) with the development consent conditions, show that mitigation measures have been implemented, and facilitate the management and control of operations.

4.7.1 Output from Step 6

A strategy for monitoring and auditing the impact of the development should be published. This should include an explanation of all the conditions and operating times as well as noise measurement requirements

5. Case Examples

5.1 Case example 1: Community Noise Impact Assessment for an Emergency Control Facility

5.1.1 Step 1: Define the project requirements, noise problem and gather technical support information

Cities require facilities to provide coordinated response to a range of emergencies that can occur. These range from natural disasters like hurricanes and forest fires and manmade disasters like major car accidents and building fires. The proposed coordinated facility was to provide:

- Main building – administration and communication control center
- Helipad, for use by emergency helicopters, and control office
- Storage and maintenance of mobile equipment
- Class room training facilities
- Outdoor training facilities for driver training and use of emergency equipment like chain saws
- On-site parking and some accommodation.

Various options for a location were considered, and the chosen one was on the edge of the town. The proposed site is adjacent to a four-lane road offering the necessary good access to the entire region. Adjacent to the proposed site was grazing broad acre farmland but is now semi-rural with smaller blocks, each with one house. Most of the residents commute daily to the town for work and manage their small farms on the weekends. They have particularly sought to live in a quiet semi rural environment.

Preliminary sketch plans for the proposal were produced for the client and these were optimized on the basis of efficient operation of the facility. Once all the elements have been defined in this way the acoustics consultant began to assess the likely noise impact.

5.1.2 Output: Main potential noise sources and key receptors

Those residing in the local area were identified as the key receptors for the purpose of the assessment. The main noise sources were identified as the helicopter operations and the outdoor training areas. Other aspects of the facility that could produce excess noise may not be so obvious; such as the air conditioning plant for the communication control center and administration block. A feature particular to the facility that has potential noise impact was the high capacity back up power supply system. When used for an emergency it is unlikely there would be noise complaints from the locals but it would also require regular testing and running to ensure its functionality.

5.1.3 Step 2: Agree on assessment criteria, establish baseline noise environment and determine extent of noise impact of initial proposal

Consultation with the various authorities was necessary to ascertain the appropriate criteria for the surrounding land uses. While some activities will be functional all the time, such as the control center, other parts of the facility, such as the training areas, may only be used on an intermittent basis. The effect from the helicopter training and operations can be over a far greater area and so over very different land uses than for the main facility. A number of different criteria were applicable and these were carefully identified. For this project, the level of the future sound was compared against the relevant established planning benchmark level, and against the level of the existing sound.

Since the potential for noise impact from a proposed development can be dependent on the initial noise environment, the baseline noise environment was firstly established using measures included in the selected criteria.

At the early stages of the assessment there were many groups working on the plan, which required changes to the layout that might have had an effect on the noise impact. Thus it is was not easy and at times would have been a waste of time and money to attempt to quantify fully the predicted noise impact at this early stage. An approximate or conceptual assessment was used to provide an estimate of the noise emission from the various components and consequently the noise immission for the surrounding areas. Comparison with the benchmark criteria showed exceedances of the benchmarks, and that the sound level increased from the baseline noise in a number of receptor areas.

5.1.4 Output: Exceedance or otherwise of criteria

The magnitude of the exceedance above the planning benchmarks and the increase in noise level was presented clearly in a summary table at each receptor.

5.1.5 Step 3: Identify and agree potential noise mitigation options

Since there was potential excess noise impact identified, the next step was to go back to the proposal and work with the other members of the team to try to optimize the proposal design on the basis of minimizing this noise impact. This led to a list of potential mitigation options.

5.1.6 Output: List of potential noise mitigation options

- A: Do nothing and keep to original proposal.
- B: Re-alignment of building profile and relocation of main plant.
- C: Relocation of the access and parking area for the facility closer to the outdoor training area.
- D: The outdoor training area moved to a more remote part of the site.
- E: Well designed noise enclosure around emergency generator.
- F: Relocation of emergency generator.
- G: Limit the times for maintenance checks of the emergency generator to times when the potential noise impact was least.
- H: For the helicopter noise, relocate associated buildings to provide some shielding for the ground operations.
- I: For helicopter noise, limit the times for ground operations and maintenance checks to times when the potential noise impact was least.
- J: Plan training flight paths to minimize overflights of residences.

5.1.7 Step 4: Assess noise impact against criteria of Step 2, and evaluate other considerations for each mitigation option.

The noise impact was calculated using the selected criteria. Additionally, each option was evaluated in terms of feasibility, practicality, cost, public interest, etc. The overall impact over all of the key receptors was summarized in the table below.

<u>Output: Summary of noise impacts and other key considerations</u>

Option	Noise Impact Assessment Will it meet the benchmark criteria?	Comments and other key issues
A	No and there will be an increase from the baseline noise level at all key receptors positions	Possibly the cheapest option but could give rise to problems with excessive noise levels.
B	Yes	This option would provide shielding, thus reducing the potential for excess noise impact was reduced.
C	Yes at 50% of receptors	This would mean a slightly longer walk to the main building but could overcome a potential noise problem.
D	Yes	This could reduce the environmental noise impact but also the noise impact on the indoor classroom training building
E	Yes	Costly. A high noise reduction enclosure for the emergency generator may be a great cost imposed for a unit that is only used intermittently.
F	No	Only reduce the noise impact by a small amount.
G	No	With appropriate consultation this option would minimize the noise impact and not impose an unreasonable cost burden on the proponent
H	Yes for only 30% of receptors	If this is done at planning stage it will have a minimal cost
I	Not fully	With appropriate consultation this option would minimize the noise impact and not impose an unreasonable cost burden on the proponent
J	Yes	This will require a little more planning but will have minimal cost implication

5.1.8 Step 5: Determine optimal noise control solution

Having established the potential impacts of each option, these were agreed with all stakeholders (including local community representative), and an optimal solution was identified weighing all the information through consultation. The response from the community was very important at this time. This project clearly had great benefit to the community as a whole. Those potentially affected were prepared to accept a higher noise impact than if the proposal was for an industry. The solution was for a combination of mitigation options (B, C, G, I, J). Limiting times of operation for certain activities needed careful consultation between the authority and the community to ensure that there was agreement. There was a means for the residents to communicate directly with the facility should the terms not be complied with.

5.1.9 Output: Record of decision process and final noise control solution

A draft impact assessment document was produced to inform the client, the authorities, the community and any stakeholders of all the potential impacts and the options for mitigation, using the outputs from the preceding steps. This document should include a record of all the options considered and a justification for any that were rejected. At the completion of the consultation process the impact assessment document was revised to reflect the outcomes and agreements. The plans were revised in accordance with the relocations. The conditions on times of operations of the plant were clearly stated along with the mechanism for dealing with complaints. Maps showing the routing for training helicopter flights were included. This document then became the document for reference by all the stakeholders.

5.1.10 Step 6: Review, implement, review, monitor and audit

The proposal (as amended by the agreed mitigation options) was implemented following a review of the assumptions, measurements and calculations leading to the final design. Documented records were kept of the operating times and of the helicopter flights. These were independently audited by the enforcement authority that also carried out spot checks.

5.1.11 Output: Monitoring and Auditing Strategy

A strategy for monitoring and auditing the impact of the development was published. This included an explanation of all the conditions and operating times, and noise measurement requirements. It was made available to the enforcement authority.

5.2 Case example 2: Noise Impact Assessment for a Road Upgrade

The following is a case study outlining the steps and outputs set out in this guideline document. It shows the long term benefits to the community that can come from a formal assessment process.

5.2.1 Step 1 - Define the project requirements, noise problem and gather technical support information

A 3km section of the main access road network for a city of around 300,000 population is single lane in each direction and close to capacity during peak periods. It is an access route to the commercial areas links into other major roads of which some are dual lanes in each direction. The road travels through existing established residential areas and there have been ongoing complaints about the traffic noise.

The traffic planners anticipated a need to allow for an increase of around 50% in the traffic volumes over a future ten to fifteen year period. The road carries around 18% heavy vehicles and this percentage was considered to remain about the same into the future.

The plan for the upgrade of the road involves construction of a dual carriageway with some straightening of the horizontal alignment to remove a bend and replacement of the steep gradient in one section by a lesser gradient over a longer distance.

5.2.2 Output: Main potential noise sources and sensitive areas

The main noise sources were identified as the road traffic noise. The residential areas on each side of the road were identified as the noise sensitive areas.

5.2.3 Step 2: Agree on assessment criteria, establish baseline noise environment and determine extent of noise impact of initial proposal

Road traffic noise criteria for residential areas in the region have been established and documented in the policy documents from various national authorities. These criteria are typically based on the 18-hour equivalent continuous A-weighted sound pressure level, centile levels or a 1-hour equivalent continuous A-weighted sound pressure level during the busiest hour of the day and apply at 1m from the façade for properties facing the road or in the private open space for those with the rear gardens exposed to the road.

Noise level measurements at selected representative locations were undertaken and showed the extent of excess and the justification for the complaints that had been received. Although the land on one side of the road rose above the level of the road, the measurements showed that the excess was limited to those properties along the alignment.

The measurement data for the current situation was used in a traffic noise prediction model to validate the model. The proposed road alignment and the estimated traffic flow data were then used to predict the noise impact over the area from the upgrade.

5.2.4 Output: Exceedance or otherwise of criteria

Summary tables and graphic representations on the plan showed the magnitude of the current and future exceedances above the planning benchmarks. This clearly identified the extent of the noise impact from the upgraded road into the residential areas.

5.2.5 Step 3: Identify and agree potential noise mitigation options

Since there was potential excess noise impact identified, the next step was to go back to the proposal and work with the other members of the team to try to optimize the proposal design on the basis of minimizing this noise impact. This led to a list of potential mitigation options.

5.2.6 Output: List of potential noise mitigation options

A: Do nothing and keep to original proposal.
B: Consider further realignments of the road to reduce the noise impact.
C: Consider road surface treatments.
D: Construct traffic noise barriers on both sides of the road.
E Provide additional noise insulation for the residents.

5.2.7 Step 4 - Assess noise impact against criteria of Step 2, and evaluate other considerations for each mitigation option

The noise impact was calculated using the selected criteria at each key receptor. Additionally, each option was evaluated in terms of feasibility, practicality, cost, public interest, etc.

Option A was agreed to be unacceptable to all parties.
Option B further realignment of the road, was investigated but the engineering constraints limited any real benefits from this option.
Option C offered a reduction that would be insufficient to reduce the exceedence.
Option D offered a practical means for mitigation to meet the criteria and there was space to construct the barriers adjacent to the carriageways. The prediction model was used to show that the barrier height would need to vary from 3 to 6 m along the alignment to meet the criteria on both sides of the road.

Option E would provide a precedent for the region and would only provide noise reduction for those inside the building when the windows and doors were closed. The noise impact would not be reduced in the gardens and outdoor living areas

Output: Summary of noise impacts and other key considerations for each mitigation option

Option	**Noise Impact Assessment Will it meet the benchmark criteria?**	**Comments and other key issues**
A do nothing	No	The cheapest option but excessive noise levels over much of the length would be in conflict with traffic noise policies for the region
B realign	Yes – only for a portion of the alignment	There was little scope for realignment and the small improvements that could be gained were only over short portions of the road
C road surface	No	This would not provide sufficient reduction (2-4 dB at the key receptors)
D barriers	Yes	A practical solution involving barriers 3 to 6 m high along the length of the road
E house insulation	Yes – if indoors	Could provide adequate noise reduction for those inside the building when the windows and doors closed but not in the gardens and outdoor living areas

5.2.8 Step 5: Determine optimal noise control solution

Having established the potential impacts and considered the practical options for mitigation the next step was to consult with the community and to present the information in a clear transparent manner. As it was considered that the barrier option was the only solution to meet with the criteria, considerable effort was put into presenting this in a clear manner for the community. In addition to plans showing the location and extent of the barrier, additional graphics provided impressions of the barrier from both sides.

As the road had some significance to the region the appearance of the barriers was considered important. It was clear from the graphics that the designers had gone to some effort to provide barriers that had some visual appeal and attempted to blend into the surrounding where possible.

5.2.9 Output: Record of decision process and PROPOSED noise control solution

A draft impact assessment document was produced to inform the client, the authorities, the community and any stakeholders of all the potential impacts and the options for mitigation, using the outputs from the preceding steps. At the completion of the consultation process the impact assessment document was revised to reflect the outcomes and agreements.

The outcome of this consultation was a complete rejection by the community of the concept of such high barriers along the road, no matter what efforts were made to improve their appearance. The community had been aware of the proposed upgrade from the first stage and was somewhat concerned about the concept of a dual carriageway. But it was not until the magnitude of the proposed barriers was made clear to them that there was such great resistance.

The output from this stage required the authorities to reconsider the entire project and effectively go back to Step 1.

5.2.10 Step 1B – Re-define the project requirements

From the previous analysis it was clear that the critical aspects for the noise were the great increase in traffic flow and the high percentage of heavy vehicles using the road. The traffic planners were required to review the usage of this access road in relationship to the road network and suggest options for reducing the overall volume and in particular the heavy vehicle portion.

The outcome of this reconsideration was that many of the trucks using the road under consideration were using it as a through route and that there was underutilization of the heavy vehicle capacity of some new roads. In effect a bypass truck route could be implemented by encouraging through traffic to use the other roads. This would require education of the current drivers to show that a longer route could take less time because of the reduction in traffic lights and in particular good signage. Intentionally leaving the current road as a single lane in each direction would also discourage vehicles into the future.

The project was redefined as an upgrade of the quality of the road but to leave it as single lane in each direction. The traffic volumes into the future would then be only increased by a modest amount and more importantly the heavy vehicles would be only 5-8%.

5.2.11 Output: Main potential noise sources and key receptor areas

The main noise sources were identified as the road traffic noise. The residential areas on each side of the road were identified as the key receptor areas.

5.2.12 Step 2B: Re-determine extent of noise impact of initial proposal

The proposed road alignment and the estimated traffic flow data was again used to predict the noise impact over the area from the upgrade.

5.2.13 Output: Exceedance or otherwise of criteria

Summary tables and graphic representations on the plan showed the magnitude of the current and future exceedances above the planning benchmarks. This clearly identified the extent of the noise impact from the upgraded road into the residential areas.

5.2.14 Step 3B: Identify and agree potential noise mitigation options

Since there was still potential excess noise impact identified, the next step was to optimize the proposal design on the basis of minimizing this noise impact. This led to a list of potential mitigation options.

5.2.15 Output: List of potential noise mitigation options

A: Do nothing and keep to original proposal.

B: Consider further realignments of the road to reduce the noise impact.
C: Consider road surface treatments
D: Construct traffic noise barriers on both sides of the road
E Provide additional noise insulation for the residents

5.2.16 Step 4B - Assess noise impact against criteria of Step 2, and evaluate other considerations for each mitigation option

The noise impact was calculated using the selected criteria. Additionally, each option was evaluated in terms of feasibility, practicality, cost, public interest, etc.

Option A was agreed to be unacceptable to all parties.
Option B further realignment of the road, was investigated but the engineering constraints limited any real benefits from this option
Option C offered a reduction that alone would be only be sufficient to reduce the exceedence over a small portion of the road
Option D offered a practical means for mitigation to meet the criteria and there was space to construct the barriers adjacent to the carriageway. The prediction model was used to show that the barrier height would need to vary from 1 to 3 m along the alignment to meet the criteria on both sides of the road.
Option E would provide a precedent for the region and would only provide noise reduction for those inside the building when the windows and doors were closed. The noise impact would not be reduced in the gardens and outdoor living areas

Output: Summary of noise impacts and other key considerations for each mitigation option – with change in heavy vehicle usage

Option	**Noise Impact Assessment Will it meet the benchmark criteria?**	**Comments and other key issues**
A do nothing	No	The cheapest option but excessive noise levels over much of the length would be in conflict with traffic noise policies for the region
B realign	Yes – only for a portion of the alignment	There was little scope for realignment and the small improvements that could be gained were only over short portions of the road
C road surface	Yes	This alone would be sufficient over a small section of the road. For the remainder the benefit gained would minimise the barrier height requirement
D barriers	Yes	A practical solution involving barriers 3 to 6 m high along the length of the road
E house insulation	Yes – if indoors	Could provide adequate noise reduction for those inside the building when the windows and doors closed but not in the gardens and outdoor living areas

5.2.17 Step 5: Determine optimal noise control solution

Having established the potential impacts and considered that the practical options for mitigation, the next step was to consult with the community and to present the information in a clear transparent manner. In addition to plans showing the location and extent of the barrier, additional graphics provided impressions of the barrier from both sides.

5.2.18 Output: Record of decision process and proposed noise control solution

The outcome of this consultation was a complete acceptance by the community of the combination of low noise road surface and roadside barriers.

5.2.19 Step 6: Review, implement, review, monitor and audit

The proposal (as amended by the agreed mitigation options) was implemented following a review of the assumptions, measurements and calculations leading to the final design. The authority undertook the necessary measures aimed at encouraging traffic to use alternate routes. The noise levels for the current traffic flow were measured following the completion of the upgrade and compared to the estimated noise levels.

5.2.20 Output: Monitoring and Auditing Strategy

A strategy for monitoring the traffic volumes and in particular the percentage of heavy vehicles using the upgraded road was developed. The strategies to discourage vehicles from using this route will be reviewed and amended as necessary.

5.3 Case example 3: Proposed residential development adjacent to existing major road and sporting facility

5.3.1 Step 1 – Define the project requirements, noise problem and gather technical support information

As part of the policy to increase the population density within the urban the local government has rezoned some areas of land for multi-story apartment development with commercial outlets at ground level. One large area is adjacent to a major road and a sporting facility with outdoor grassed playing areas. When there are existing noise-producing land uses the responsibility is on the new development in the area to provide whatever noise mitigation is required.

Preliminary sketch plans for the new residential proposal were produced for the client and these were optimized for the developer on the basis of the maximum number of residential units that can be placed on the area. The acoustics consultant began to assess the likely noise impact from the various noise sources in the area.

5.3.2 Output: Main potential noise sources and key receptors

The main noise sources were identified as the road and the outdoor sporting areas.

5.3.3 Step 2: Agree on assessment criteria, establish baseline noise environment and determine extent of noise impact of initial proposal

Consultation with the various authorities was necessary to ascertain the appropriate criteria for the residential development. As these were to be multi-story apartments with balconies the applicable criteria were at one m from the façade on the balcony inside the bedroom with the windows closed.

Data on the traffic flows for a time 10-15 years ahead was used with appropriate traffic noise prediction programs to determine the noise impact on the site from the road. These indicated that there would be an excess for the apartments facing the main road.

The noise levels in the vicinity of the outdoor sports fields were monitored over two weeks. The noise levels were a little elevated during the time of use of the fields but this was only during the day. Comparison with the applicable criteria indicated that along the boundary of the site the applicable criteria would not be exceeded.

5.3.4 Output: Exceedance, or otherwise, of criteria

The magnitude of the exceedance above the planning benchmarks was identified for the part of the proposed development facing the major road

5.3.5 Step 3: Identify and agree potential noise mitigation options

Since there was potential excess noise impact identified, it was necessary to work with the developer and the architect to develop appropriate mitigation measures

5.3.6 Output: List of potential noise mitigation options

A: Do nothing and keep to original proposal.
B: Re-alignment of building profile
C: Construct a mound along the boundary facing the road
D: Incorporate a higher level of noise reduction in the façade for the apartments facing the road.

5.3.7 Step 4 - Assess noise impact against criteria of Step 2, and evaluate other considerations for each mitigation option

The noise impact was calculated using the selected criteria. Additionally, each option was evaluated in terms of feasibility, practicality and cos. The overall impact over all of the key receptors was summarized in the table below.

Output: Summary of noise impacts and other key considerations

Option	**Noise Impact Assessment Will it meet the benchmark criteria?**	**Comments and other key issues**
A	No	Cheapest option but will not be accepted by the authority.
B	Yes	Distance involved to achieve sufficient mitigation and reduction in the number of apartments would be unacceptable to the developer
C	Yes for those at ground level	This would provide restrictions on access and would only benefit a small portion of the development
D	Yes	This could reduce the noise levels in the bedrooms to meet the criterion. The few balconies that were in excess could have openable transparent screens for the balcony that could be closed when the traffic noise was excessive. There would be an excess cost.

5.3.8 Step 5: Determine optimal noise control solution

Having established the potential impacts of each option, these were agreed with all stakeholders (the developer and the authority) Although there would be a cost for the additional sound insulation it would be limited to those apartments facing the road.

5.3.9 Output: Record of decision process and final noise control solution

The impact assessment document was produced for the records of the authority and the developer.

5.3.10 Step 6: Review, implement, review, monitor and audit

The authority ensured that when the planning approval documentation was submitted the additional noise insulation was clearly identified and that the extent complied with the impact assessment document.

5.3.11 Output: Monitoring and Auditing Strategy

The provision of the higher-level sound insulation was checked as part of the building inspection process.

6. Conclusions and Summary

The primary objective of the TSG 6 was to provide practical guidance to those involved with regulation and control of community exposure to environmental noise, excluding the noise generated by neighbors. This report has focused on providing guidelines outlining the steps to be followed when performing an effective community impact analysis. It advocates a flexible approach to the control of exposure to environmental noise in a community through informed choices.

This report has discussed the need for guidelines on Community Noise Impact and identified issues to be considered in practical community noise impact assessment. A framework for the guidelines for community noise impact assessment has been presented with three case examples used to demonstrate the principles.

The principles outlined in this report or purposefully general in nature allowing for local implementation to take account of differing policy regulations and criteria.

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Appendices

Appendix A:

State-of-Knowledge Concerning the Effects of Community Noise

The following text is provided as it was published as an excerpt from the International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection (CAEP) 2009 report entitled "Assessing Current Scientific Knowledge, Uncertainties and Gaps in Quantifying Climate Change, Noise and Air Quality Aviation Impacts". This report is available for downloading from: http://web.mit.edu/aeroastro/partner/reports/caepimpactreport.pdf. Although the focus of the ICAO CAEP Workshop in Montreal during October 2007, which resulted in publication of this report, was on aircraft issues, the information below on the effects of aircraft noise on communities will generally be applicable to other community noise sources, particularly other transportation noise sources.

"Current State of Knowledge" - ***Understanding the Effects of Aircraft Noise on Communities***
For the past half century, various researchers and agencies have sought to quantify the effects of noise, particularly aircraft noise, on people and communities. In general, a consistent course of scientific investigation has been followed. This course may be thought of has having what might be described as the three basic steps of a scientific process:

1. Identify the effect of interest

   - Community annoyance
   - Sleep disturbance
   - Cardiovascular & other non-auditory physiological effects
   - School learning & academic achievement in children
   - Speech/communication interference
   - Mental health
   - Effects of noise on adult work performance
   - Effects of noise on residential behaviour
   - Complaints or community actions (as a response to stress caused by one or several of the effects stated above)

2. Design and conduct an experiment, usually of the form:

   - A statistically based exposure-response relationship, either through surveys eliciting self-reports of effects, or through epidemiological studies that include objective measures of responses (e.g., blood pressure readings)
   - Laboratory experiments to reveal basic physiological responses (awakening, task interference, speech interference)

3. Analyze the results, compare with other similar research results, determine validity/ability to generalize results, and publish.

The Noise Panel discussed the results of these efforts and focused their attention on exposure-response effects of aircraft noise agreed to have significant numbers of studies that yielded fairly consistent results. Table 4.1 summarizes the current state of knowledge as identified by the Noise

Panel and may generally be considered as supported by consensus. This table includes reference to recent results from epidemiological studies showing the effects of aircraft noise on arterial hypertension.

The Noise Panel found quick consensus on the noise effects that have had substantial exposure-response exploration, and these are given in the first column of Table 4.1; the final column indicates the consensus for readiness for use in quantifying effects and for ICAO States developing policy. In cases where exposure-response data exist, the panel's assessment that there is "sufficient" level of certainty for use implies that methods exist for computing response (effects) given an exposure. The Panel had a lengthy discussion on what is called the "Computational Cut-off," column 5. The values in this column represent the consensus level below which data suggest the probability of adverse effects is sufficiently low for urban / suburban settings for civil airports. Nevertheless, there may be persons living in areas subject to noise exposure below these values who consider themselves seriously affected by aircraft noise. These values serve as guidelines for where computations for urban/suburban noise impact analyses could begin. This qualification was felt necessary to avoid the perception that these "computational limits" would apply in rural or natural areas and to airports with few or no jet operations. The Panel also wanted to be clear that this cut-off is not intended to suggest a policy decision of levels at which impact occurs.

One complexity not explicitly identified in the table is that there did not appear to be complete consensus on the meaning of "sufficient" in the last column. Participants may have been considering different data or different interpretations of the data when they agreed the data were sufficient. Hence, to finalize the practical application of the data, some decisions will be necessary to select which data or which interpretations to use. Alternatively, more than one data set or interpretation could be used to quantify the effects of policy alternatives and the results compared to determine the sensitivity of the outcome to the specific choice.

Another noise-related effect not listed in Table 4.1 is depreciation of house values in areas surrounding airports (see e.g., the discussion provided by Nelson, 2004) and the concept of Disability Adjusted Life Years (DALY). Though these topics were discussed, and the methods (such as hedonic pricing) are rigorous, there was no consensus that the costs of noise or the benefits of noise reduction could be monetized in a way that properly reflects the effects of noise on people. In order to address questions related to the effects of aircraft noise, specific summaries were provided for each of the most well understood topic areas to establish the current state of knowledge and to guide the Workshop discussions. These summaries on separate noise effects were updated after the Workshop, and are available on the Workshop website.

- Community Annoyance
- Non-Auditory Physiological (Cardiovascular) Health Effects
- Sleep Disturbance
- Valuation of the benefits of aircraft noise reduction
- Effects on Children Cognition and Health

Additional Concepts for Understanding Effects, Adverse Effects and Impacts

Noise exposure

Noise Exposure is a physical phenomenon that can be quantified by noise metrics, such as those given in Table 4.1. It is possible to measure the amount of noise daily experienced by a moving person through the use of a dosimeter, but determining aircraft noise exposure is place specific and accomplished either through detailed modelling or with sophisticated noise monitors. The term "exposure", itself, concerns only the description of sound levels received by community locations, not the "effects" of such levels.

Table 4.1 – Assessment of Metrics and Exposure-Response Curves Available for Aircraft Noise Impact Analyses

Noise Effect	***Primary Noise metric***	***Other Metrics***	***Exposure-response curves***	***Computational Cut-off (for major civil airports in urban/suburban settings)***	***Notes***	***Level of certainty for use in impact assessment (1)***
Community Annoyance	L_{dn}, L_{den}	No. of events	Several exposure-response curves exist, but they may need updating to reflect the current situation - Also need information from Asia & developing countries	40-45dBA L_{dn} or L_{den} Need to consider separating day & night	55dBA - Level for identifying where potentially serious annoyance begins Several non acoustic factors affect annoyance: Communications with residents People feeling empowered Degree of trust in the airport	Sufficient
Sleep Disturbance /Awakening	At ear LAmax Or SEL + number of events - - - - Lnight	n/a	Several curves are available for predicting awakenings	Indoors 33dBA LAmax (beginning of effect)	Awakening also depends on the time between events and on the time of night of the events	Sufficient
Sleep structure	L_{eq} for sleep period	n/a	Very limited evidence	No evidence	Few studies based on limited data. Further research needed	Limited
Hypertension	L_{eq} (24), Lnight	n/a	Suggestive but data needed from latest study (HYENA: Jarup 2008)	Hypertension: 55 dBA		Sufficient
CHD: Coronary Heart Disease	Leq(24), Lnight	n/a	Evidence for road traffic but awaiting evidence for aircraft (HYENA: Jarup 2008)	60-65 dBA Leq outdoors Effect of events/day not known	Air pollution is confounding factor	Limited
Cognitive performance and academic	LAeq(8)	Researc h needed	RANCH: Stansfeld 2005, Clark 2006,	No thresholds, but above 50-55dBA Leq –	Exposure to aircraft noise at night also	Sufficient

Noise Effect	*Primary Noise metric*	*Other Metrics*	*Exposure-response curves*	*Computational Cut-off (for major civil airports in urban/suburban settings)*	*Notes*	*Level of certainty for use in impact assessment (1)*
performance of children		on a number of events measure	Van Kempen 2006 exposure-effect associations for reading	refer to WHO	contributes to academic performance reduction or impairment	
Speech and Communication Interference	SIL, AI, LAmax (for speech interference), NAT, Time above	Spectra			Contributor to annoyance & cognitive performance - Need improved metrics for communication interference	Sufficient

(1) through the strength of evidence

Noise Effects / Adverse Effects / Noise Impacts

The human responses to noise exposures are the effects; when the level of the noise exposure increases, the type of response given by a person or a population can vary between an adaptation response for low noise doses, to repairable damage which disappears when noise stops, or irreparable damage after severe exposure (Rylander & Megevand 1993). Exposure to night-time noise may provoke primary effects during the sleep, or possibly secondary effects (after effects) such as decreased performance. Long-term effects may also be possible.

The concept of “adverse effects” of noise on health is used here to identify the point at which effects reach a level that corresponds to an increased risk to public health and welfare. The concept of this risk to health and welfare was not fully vetted by the Noise Panel or was any consensus approach articulated, see Section 4.2. Many adverse effect inventories have been done and generally include potential auditory effects (primarily only for occupational environments), emotional responses such as annoyance, cardio-vascular system responses such as hypertension and cardio-vascular disease processes, immune system responses, and effects on the digestive or neuro-endocrine systems. Exposure-response relationships are usually established between specified levels of noise exposure and various health effects. The simplest presentation consists of an exposure-response curve (referenced here in Table 4.1, fourth column) which is a graphical representation of exposure relationship. These curves can be used to assist in the selection of the “critical health effects threshold levels” (impacts), which are the lowest noise levels at which important (i.e., “significant”) effects are judged to appear. This notion of the “importance” of the effect is often discussed in assessments of noise impacts, although it is acknowledged that the choices for these “threshold levels” is always subjective and arbitrary, and hence must be a policy decision.

Specific health effects have been studied separately in many research studies, and exposure-response functions have been calculated showing noise levels that correspond to various effects such as sleep disturbance, hypertension, annoyance, etc. A global view of specific effects still typically lacks an assessment of the combination of direct and indirect effects: this broader concept provides a description of the total “health impact” [Franssen et al, 2002]. For example, in the

Amsterdam case study (Franssen et al 2002) noise, air pollution, odours and radar are all considered in a health impact study.

ICAO's goal is to limit or reduce the impacts of aircraft noise. The word "impact" is not used only for noise, but applies to all three topics: Noise, Local Air Quality and Climate Change. For noise, specifically, the number of people exposed to a specified level of noise is the simplest way to describe aircraft noise impacts. This use of exposure can be a useful concept, but it is inadequate to understand, predict, manage and mitigate the actual "effects" of aircraft noise on communities. Strictly speaking, if we intend to compute the number of people affected we should be using the exposure- probability. The distinction between "exposure" "effects" "adverse effects" and "impacts" is crucial for the aircraft noise arena.

Identifying Exposure Levels at which Impact Occurs

Considerable scientific data have been published on the consequences of excessive noise exposure, especially those described in Table 4.1. Traditionally, authoritative reviews of the noise effects literature predominantly emphasize community annoyance, sleep disturbance, and non-auditory physiological health effects (primarily cardiovascular effects), and some provide recommendations for target noise exposure criteria (i.e., guidelines) for the avoidance of those effects, such as those recommended in the WHO "Guidelines for Community Noise [WHO, 2000]. It is important that up-to-date exposure-response relationships be available to decision-makers to provide the required scientific foundation for choosing response relationships and computing the affected numbers across the whole population. Affected people are a part of exposed population: there is no full causality between exposure and effects, only a risk, a benchmark noise exposure criterion. Because most adverse effects do not commence at a clear point in any exposure-response relationship, suggestions by the scientific community for levels that are chosen to "fully protect" people from the most severe adverse effects of exposure are generally provided only as noise guidelines, rather than as noise policy regulations or standards, with the guidelines being used as a "best effort" context and the latter being used to describe legally identified levels at which "impact" occurs. It is also important to remember that the choice of a noise exposure guideline is ideally based on the consensus of the international scientific community expressed through committees at WHO, ISO, ICBEN, FICAN and others, and their understanding of the available data relating exposures to responses. Well-considered and up-to-date exposure-response relationships provide the most useful data, and the Noise Panel has identified in Table 4.1 the effects that have sufficient certainty for use in identifying policy thresholds of impact.

It is important to recognize that recommendations or guidelines such as those provided by the WHO are for ideal exposure levels. There are many situations, however, where there is little realistic possibility of achieving these benchmarks. It is important to recognize the difference between ideal noise exposure goals, which, are designed to protect the public health with an adequate margin of safety and noise exposure goals which are technically feasible and affordable. In developing national and international determinations of "impact," a balance is needed between the recommended "ideal" noise exposure guidelines and goals, such as those provided by the WHO [WHO, 2000], and the practical and financial realities of achieving these goals.

Uncertainties in Knowledge

Many uncertainties often appear in the scientific literature on environmental noise, including uncertainty in both the reported noise exposures and the individual or community responses to these exposures. Of course, at both the individual and community levels, variability is not the same thing as uncertainty, but they are often closely related to each other. Large variability may be a result of measurement difficulties – for example, people's noise exposures are difficult to determine – or a result of inevitable differences – people react differently to identical noises. In the former, variability coincides with uncertainty, while in the latter, variability is a fact of life. Variability, for whatever reason, however, does not mean that a curve fit to the data is uncertain. Simply by acquiring large numbers of data points, the uncertainty of a curve fit can be quite small indicating high confidence in the average of the data. This certainty, however, may say nothing about the curve's use in predicting how a given community or given person will react to the noise exposure, especially when the variability (scatter) of the data is large. Uncertainty in predictive ability should not be confused with the uncertainty associated with a curve fit to the data.

At a minimum, the large variability observed in the most commonly accepted meta-analyses, such as those for community annoyance and sleep disturbance, leads to a large uncertainty in the accuracy of the exposure-response relationships when used as predictive tools. Statistical measures (such as the variance, the standard deviation, and the standard error of a correlation coefficient) describe the amount of variance accounted for by a prediction curve. They are technically indicators of the variability of the data, but may also be indicative of the amount of uncertainty in a data set.

Several factors can contribute to the uncertainty of the data on human responses to noise. One reason that there is considerable uncertainty about the actual individual exposures of subjects in most community response field studies is because noise measurements (or computed exposures) are typically made outdoors even though the participants are often inside and moving around their homes. Community annoyance field studies are most prone to this source of uncertainty. Not only is there considerable uncertainty introduced because of individual home differences in the outdoor-indoor transfer functions due to difference in home construction techniques, insulation capabilities, but also because of lifestyle differences which determine whether the study participants live with their windows open or closed. There are also differences between studies concerning the microphone position and the different sides of a home which can yield different measured sound levels. This lack of consistency in the measurement techniques can be a major source of uncertainty about exposure.

Probably the largest source of uncertainty in describing individual study participant exposures involves the mobility of the participants throughout the home during the measurement period. It is fairly obvious to state that, as people move throughout their homes, their individual exposures will vary considerably – leading to considerable uncertainty about their exposures. Also, often participants who work some distance from the home and are not even there during the period of exposure are included in community response studies of annual exposures.

The U.S. Air Force meta-analysis (Finegold, et al., 1994) of the existing published community annoyance data showed considerable variability of responses within and across studies, as shown in Figure 4.1. Figure 4.2, below, shows the variability and, hence, the associated uncertainty in the same database as a predictor of annoyance at the critical 65dB A DNL exposure point.

There are several reasons why such variability is observed. One reason is that, when a specific source of noise, like aircraft noise, is studied, exposure to other sources of noise is not taken into account.

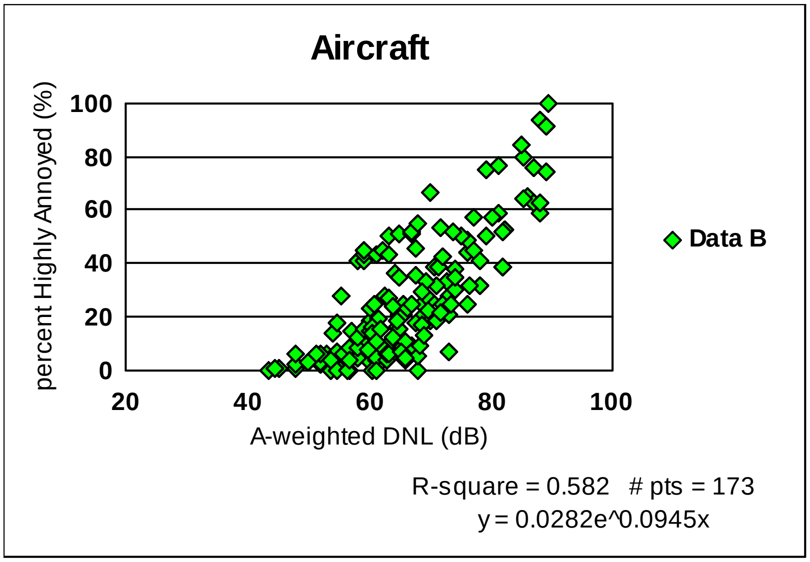

Figure 4.1. Data scatter for community annoyance in response to aircraft noise exposure (Finegold et al., 1994).

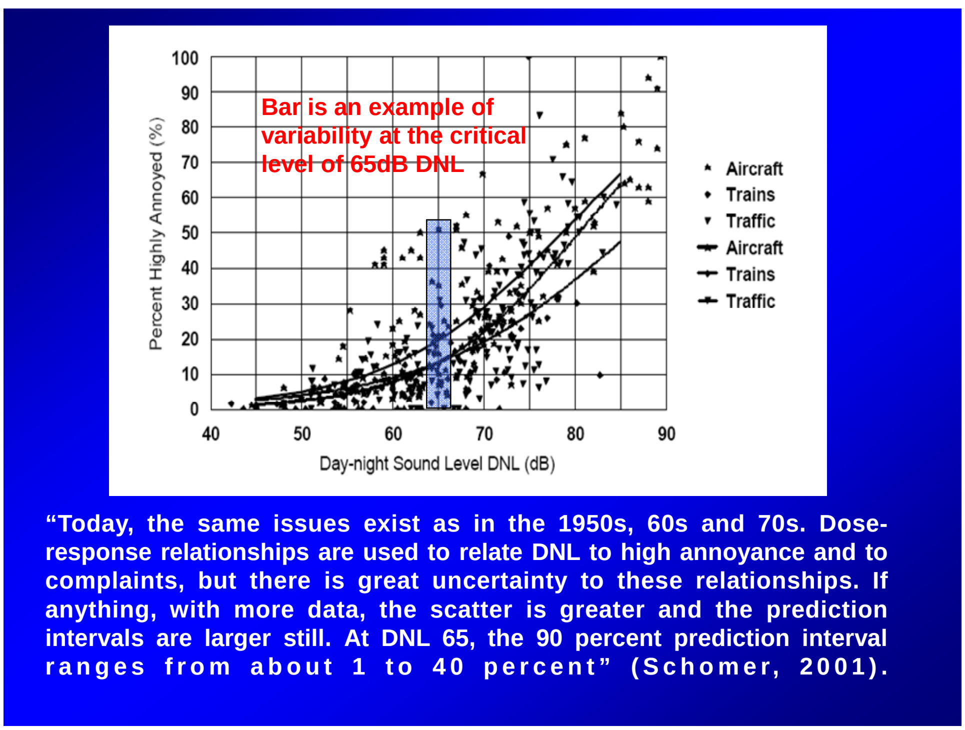

Figure 4.2. Community Annoyance - data variability at 65dB (A) DNL (modified from Schomer, 2001).

A second factor consists of the large difference in the auditory performance in humans, represented by the hearing threshold, which can differ across individuals by as much as 20dB. To an unknown extent, this variability shows up in the standard deviation of human responses to noise across study participants. This variability in hearing acuity is well-known and accepted by the scientific community, but it makes the adoption of guidelines for noise control difficult.

Another source of variability within and between studies is the existence of both individual and community-level tolerance for various types of noise exposure, and thus the acceptability of various noise exposures. For example, it has been known for a long time that community responses to noise, such as exposure to aircraft noise, are highly correlated with various socio-economic factors. Without going into detail on this topic, it should suffice to say that this community-level bias is a major source of the variability observed between various field studies. This makes it difficult to develop a single exposure-response curve which applies to all communities because of this source of uncertainty in predicting how a community will respond to aircraft noise.

Despite these obvious sources of variability and uncertainty, the Noise Panel considered that a sufficient level of knowledge exists to develop and promote exposure-response relationships relating community responses to aircraft noise, particularly for community annoyance, sleep disturbance, hypertension, cognitive performance and speech interference.

Findings

The Noise Panel found that there are currently well-documented exposure-response relationships, with varying levels of international scientific consensus, for each of the effects listed in Table 4.1, which are ready for immediate application in the overall aircraft noise impact assessment process, except for sleep structure and coronary heart disease (CHD). Table 4.1 gives the consensus on readiness ("sufficient" is ready, "limited" is not). It does not indicate, however, which data and what interpretation of the data is "sufficient" for immediate application. Differences of opinions clearly existed within the Panel for interpretation of Community Annoyance data and Sleep Disturbance data. Hypertension data were discussed, but interpretation and which data should be used was not addressed.

Concern was raised at the Workshop about the applicability of the commonly accepted, predominantly Western exposure-response relationships to all countries and all geographic areas of the world. A presentation by a noise expert from Japan showed that additional research is needed, particularly in Asia but elsewhere as well, to examine cultural differences in expectations concerning the acceptability of aircraft noise, such as cultural differences in community annoyance due to these exposures.

The Noise Panel found that because air traffic has evolved from fewer operations with individually loud aircraft to more frequent operations with quieter aircraft, updated exposure-response curves are needed to better reflect current and projected air traffic operations. There was no indication that lack of such updating due to the time and effort required should prevent use of the presently available information.

The CAEP process of assessing aircraft noise impacts is currently based on only the number of people exposed to significant noise as measured by Day Night Average Sound Level (DNL). The Noise Panel found that there is no compelling reason to abandon the use of DNL or Lden (in Europe).

A large majority of the Noise Panel found a clear consensus on definitions of health or welfare effects according to the WHO definition, but consensus was less clear on whether these effects should be separately defined or combined.

The Noise Panel found that cost-effectiveness analyses and cost-benefit analyses are potentially valuable tools for use in assessing the effects of aircraft noise. However, many Noise Panel members' lack of either familiarity or experience with the metrics and techniques meant consensus could not be reached on which analytical techniques are the most valuable ones to be used. The Noise Panel generally found that additional monetary impacts beyond only the traditional effects of housing prices would be useful, including the monetary impacts of health and education effects.

The Noise Panel experts generally found that economic assessment of noise effects is currently quite challenging and no broad consensus exists concerning how this should be done. Economists presented the state-of-the-practice in noise effect valuation, based on housing value loss and contingent valuation surveys. However, many among the Noise Panel participants expressed their concern that such economic impact models fail to capture the full extent of noise effects, such as the value of cardiovascular effects and the effects of sleep-disturbance on worker productivity and worker accidents. Some panellists noted that QALY and DALY (Quality-Adjusted Life Years, or Disability-Adjusted Life Years) analyses were also applicable to noise and had been used to compare noise and air quality impacts in airport analyses. However, other panellists felt that these methodologies were not yet widely agreed upon sufficiently for use in aircraft noise impact assessments. Ultimately, on the one hand most of the panellists noted that they did not have economic expertise, making it difficult to draw solid conclusions on this topic. On the other hand, monetization of health effects, education and training, and of the effects on houses pricing appears to be a possible common metric to assess the impacts of airport noise, air pollution and possibly climate change.

References for Appendix A

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Appendix B:

Examples of Exposure-Response Functions and Benchmark Criteria[2]

A. Community Annoyance

Various attempts have been made to assess the effects (measured by average reported annoyance, sleep disturbance or a similar type of effect) from exposure to community noise (measured by long term average sound levels) and to develop exposure-response relationships. As individual reactions to noise are quite varied, these types of studies need large sample sizes to obtain reasonable correlations between the noise exposure and the responses of people in affected communities. Any exposure-response relationship determined from large studies over a range of communities and cultures will not necessarily represent the reaction of individuals or small communities. However, these exposure-response relationships are of great value for macro-scale strategic assessment purposes where individual differences are not important and have been used for many decades in environmental noise impact assessments around the world.

A typical example of an exposure response relationship is that shown in Figure B1 from Finegold et al. [1], showing the percentage of respondents in social surveys that have indicated a “highly annoyed” reaction for the range of noise levels which are shown, averaged over the day and the night. The shape of this curve shows that for any noise level there is only a portion of the community that is highly annoyed and that this portion of the community does become larger as the noise level increases, but it also highlights the dilemma facing authorities who try to use this for assessing the impact from current or future projects by selecting a point on such a curve which separates acceptable from unacceptable community impacts. As Section 3 of this report highlighted previously, a noise exposure criteria or benchmark can be defined as an exposure level above which a significant impact is predicted. Thus, a noise exposure criterion is one point on a general exposure-response relationship nd the choice of where this point lies on an exposure-response relationship is by no means easy to select because it is always an arbitrary point and is affected by the social costs of noise effects versus the cost and technical feasibility of achieving any particular level of exposure in a community. Thus, the choice of an exposure criterion along an exposure-response curve is always ultimately a political decision.

Additional exposure-response relationships using meta-analysis data from published social surveys of community annoyance include those of Fidell *et al.* [2], shown in Figure B2 in comparison with the original Schultz Curve [3], the major update of Miedema *et al.* [4-5], shown in Figure B3, and the more recent update by Fidell & Silvati [6], shown in Figure B4 in comparison with the Miedema *et al.* curve [4-5] for aircraft noise. Although the exposure-response relationships presented here rely heavily on data from field studies of exposure to aircraft noise, the existing databases do contain data from other transportation modes and are generally agreed to be valid for use in predicting and understanding the effects of a variety of

[2] Although several examples of both community noise exposure-response relationships and exposure criteria guidelines are presented in this Appendix, the International Institute of Noise Control Engineering does not recommend any of these specific prediction curves or exposure criteria for adoption by various countries. The choices of which of these to adopt is left to the decision-makers in each country and other alternatives are available. The ones presented here are only examples of what is available, although each has its own supporters in the scientific community.

community transportation noise sources, including at least aircraft, highway and regular railway noise.

The sequence of meta-analyses described above represents a continual growth in the data available relating transportation noise exposure and community annoyance in response to these exposures, as well as an improvement in the sophistication of the meta-analyses used to describe these data. Although the same debates continue today as those originally conducted decades ago between the early community annoyance research, such as Schultz and Kryter, the results of the various meta-analyses reported on here have more in common than they show significant differences. Our understanding of community annoyance and the adequacy of the various curves proposed to predict community annoyance for future community development projects speaks well for the growth of the environmental noise research community. Although the most recent analyses of Miedema and associates at the Netherlands Organisation for Applied Scientific Research (TNO) might very well stand the test of time, more open dialog and debate, along with freely sharing data between researchers, would lead to the development of a true international consensus on the various technical issues involved in choosing a final set of exposure-response relationships for use in environmental impact analysis. Because of the potential cost and technical issues involved in implementing government noise exposure policies, as well as the political considerations in these decisions, the environmental noise research community needs to work on developing this much needed consensus.

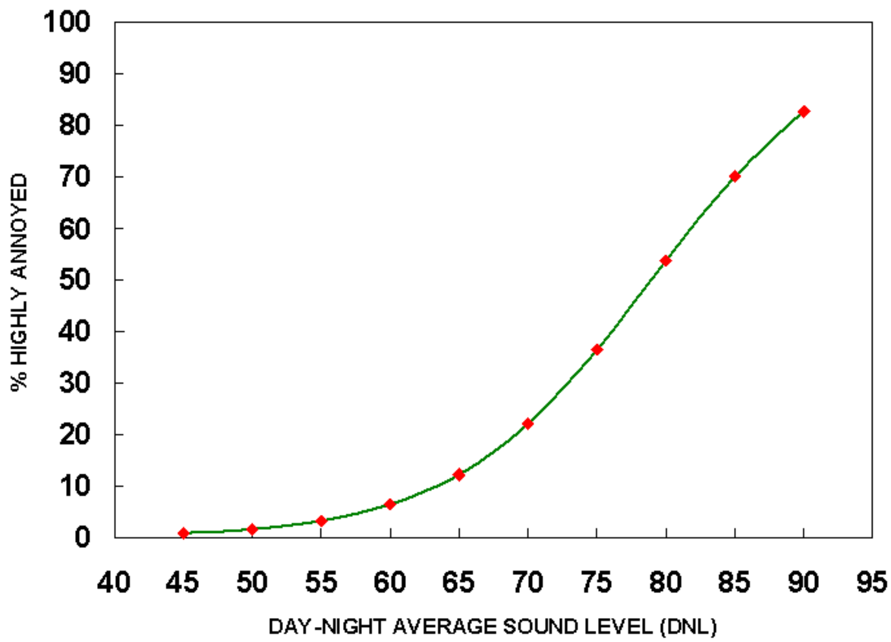

Figure B1. Community annoyance exposure-response curve from Finegold *et al.* [1]

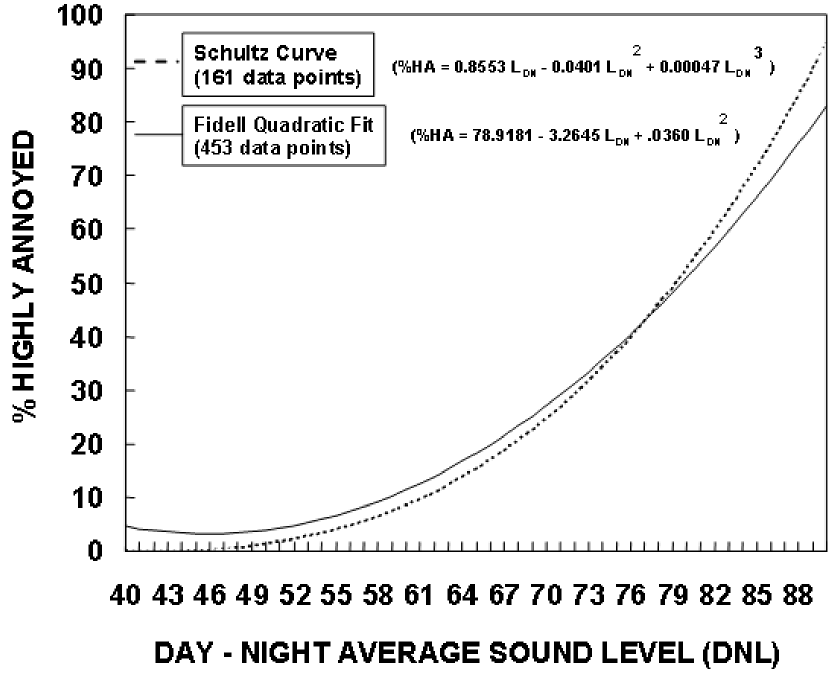

Figure B2. Community annoyance prediction curve from Fidell *et al.* [2], compared with original Schultz Curve [3]

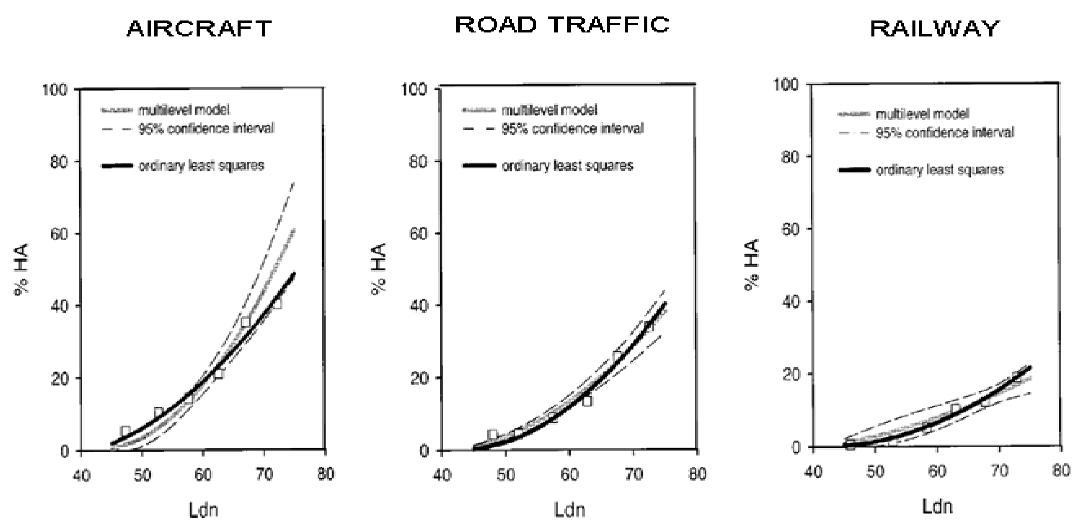

Figure B3. Miedema *et al.* [4] Community Annoyance prediction curves

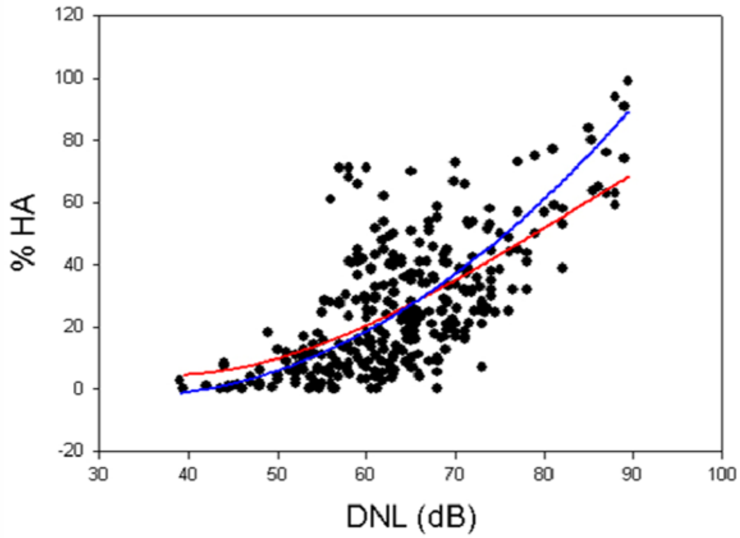

Figure B4. Scattergram of exposure-response relations, together with the (red) logistic regression curve for aircraft noise annoyance according to Fidell & Silvati [6], and the (blue) regression curve of Miedema & Vos [4] for aircraft noise. Note that the definition of “highly annoyed” is: 60-80 % of the length of the response scale.

B. Sleep Disturbance

Similar to the efforts described above for developing exposure-response relationships for community annoyance, established meta-analysis techniques have also been used to develop similar curves for predicting sleep disturbance from exposure to nighttime noise, particularly aircraft noise. Sleep disturbance is a common effect described by most noise-exposed populations and their complaints are often very strong, especially around airports. Protection of this particular rest period is necessary for a good quality of life, as daytime well being often depends on sleep quality and efficiency. Reduction or disruption of sleep is detrimental in the long term since chronic partial sleep deprivation induces marked tiredness, increases a low vigilance state, and reduces both daytime performance and the overall quality of life. Sleep appears to be quite sensitive to environmental factors, especially noise, since external stimuli are still processed by the sleeper sensory functions although there may be no conscious perception of their presence. The large amount of research published during the last 30 years has produced considerable variability of results and often some are quite controversial.

The absence of one internationally accepted exposure-response relationship is largely due to the lack of one obvious “best choice” research methodology, as well as to the complex interactions of the many factors which influence sleep disturbance. These include differences in the characteristics of the noise itself, differences in individual sensitivities, differences in attitudinal biases towards the noise source, and the context of the living environment. Current exposure-response relationships from major published meta-analyses use either “awakenings” or “body movements” to describe sleep disturbance. For brevity, this summary paper will focus predominantly on these meta-analyses, while recognizing that there are a great many individual studies published over the past decade which provide considerable sleep disturbance data using a wide variety of research techniques. Below are several of the more-commonly referenced approaches and exposure-response relationships for sleep disturbance.

In Europe, in July 2002 the European Commission (EC) published the “EU Directive on the Assessment and Management of Environmental Noise” (END) [7]. This EC regulation specifies *Lnight* as the indicator for sleep disturbance, although a required response measure for sleep disturbance has not yet been selected. As part of developing the END, the European Commission contracted the Netherlands Organisation for Applied Scientific Research (TNO) to derive exposure-response relationships between *Lnight* and sleep disturbance for transportation noise, which will be included in a future Annex to the END [8, 9 10]. TNO recognized that outdoor night-time noise exposure at the most exposed facade of a dwelling *(Lnight*) is not the only acoustical factor that influences sleep disturbance. Therefore attention is being given to the role of other factors, notably the actual noise exposure at the façade of the bedroom, and the difference between outdoor and indoor noise levels (sound insulation) of bedrooms. There is also concern about whether using only a metric which describes the whole night exposure, such as *Lnigh*t, is sufficient or whether an individual event metric is also needed. As an alternative approach, Vallet [11] has argued for a supplementary indicator, *Lmax*, to be used in addition to *Lnight*.

In the recent review of nine published studies on awakening by noise by Passchier-Vermeer [10], it was found that there were several different definitions of “awakening”. In that review, however, all awakening data were collected on behavioral awakening; namely, awakenings that were followed by an action, such as pressing a button. The number of awakenings defined in this manner is much smaller than the number of sleep stage changes which lead to EEG-patterns similar to wakefulness. Data were included for rail traffic noise, ambient (probably road) noise, civil aviation noise and military aviation noise. However, data for civil aviation noise, from seven studies comprising 174,000 aircraft noise events experienced by over 1,000 subjects, were sufficient to derive the following dose-effect relation:

$$\text{percentage of noise-induced awakenings} = -0.564 + 1.909 * 10^{-4} * (SEL_{inside})^2 \qquad [1]$$

where SEL_{inside} is the Sound Exposure Level (SEL) of an aircraft noise event inside the bedroom. With this relation, it was possible to calculate the expected number of noise-induced awakenings for an individual L_{night}. This approach requires that all single contributions over the year to this L_{night} be known. Alternatively, if a future situation has to be estimated for which the exact data are available) a worst case scenario can be calculated. Figure B5 represents the results of this worst case approach (with SEL converted to Lnight), showing the maximum number of awakenings n_{max} that may be expected (from European Commission [12]).

nmax= 0.3504*10(Lnight-35.2)/10 [2]

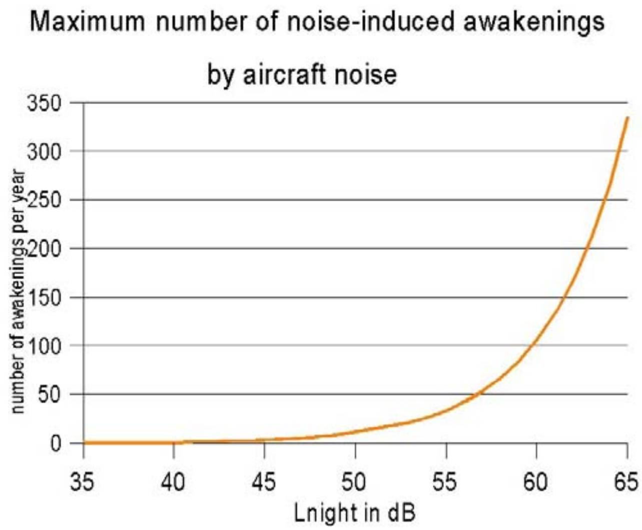

Figure B5. "Worst case" prediction of noise induced behavioral awakenings per year using Lnight, converted from inside exposure data [12], based on data from Passchier-Vermeer [10]).

The European Commission Position Paper [12] on night-time noise also points out that "It should be noted that, on average, 600 spontaneous awakenings are reported per year. This also explains why so many more awakenings are reported than can be attributed directly to aircraft noise. At 55 L_{night}, nearly 100 overflights per night with $SEL_{,inside}$=58.8, or 1 per 5 minutes are possible. It is therefore very likely that an overflight coincides with a spontaneous awakening.

In the TNO analysis, relationships were developed between noise-induced increase in motility (*m*) or noise-induced increase in onset of motility (*k*) in the 15-s interval following the maximum noise level of an overflight, using indoor exposure levels (*Lmax** or *SEL**). Although the TNO reports contain several versions of the derived exposure-response relationships, for simplicity only one is presented here. Figure B6 shows a plot of the probability of (aircraft) noise-induced motility (m) in the 15-s interval at which indoor maximum noise level occurs as a function of Lmax*, for various levels of long-term aircraft noise during sleep period (Lnight*). Other determinants of the relationships between instantaneous motility and *Lmax** or *SEL** are the point of time in the night, and time since sleep onset; e.g., after 7 hours of sleep noise-induced motility is about 1.3 larger than in the first hour of sleep. Age has only a slight effect on noise-induced motility, with younger and older people showing a lower motility response than persons in the age range of 40 to 50 years. Discussion will continue for some time concerning the use of single event versus whole-night exposure indicators and whether the time of night also needs to be considered. In the TNO analysis *no relationship could be assessed between Lnight and self-reported sleep disturbance on the basis of the analysis of aircraft noise surveys*. Thus, future use of self-reports of movement, awakenings, or other effects needs serious reconsideration because of the questionable validity of self-report data for predicting actual responses to noise events.

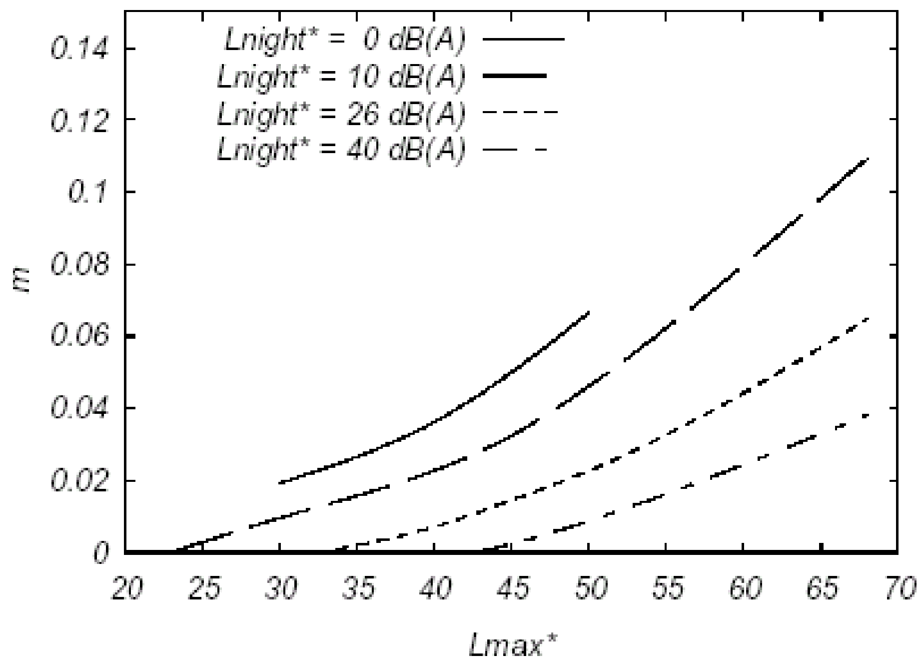

Figure B6. Probability of (aircraft) noise-induced motility (*m*) in the 15-s interval at which indoor maximum noise level occurs as a function of *Lmax**, for various levels of long-term aircraft noise during sleep period (*Lnight**) [8].

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In the USA[3], the standard for predicting noise effects on sleep is ANSI/ASA S12.9 Part 6 — Methods for Estimation of Awakenings Associated with Outdoor Noise Events Heard in Homes [13]. This standard has been recommended by the USA Federal Interagency Committee on Aircraft Noise (FICAN) as the method to use to assess airport noise awakening potential [14]. It is based on work by Anderson and Miller [15] and is predicated on the use of "behavioral awakenings" as the fundamental response metric. "Behavioral awakenings" means that the individual is awake enough to press a button, and, worldwide, there have been eight major studies on the effects of noise on sleep that included the study of behavioral awakenings [16-23]. These eight studies all provide data that relate the probability of being awakened to the sound exposure level (SEL) of the individual noise events. The standard is based on these kinds of data that permit prediction of the likelihood of behavioral awakenings in response to unique, single events, but analyzed this way, these data do not immediately provide a means to predict the effect of an ensemble of events distributed in some fashion throughout the night. It is the Anderson and Miller work [15] that provides this means.

The method determines the number of people or percent of the population likely to be awakened at least once from a full night of noise events. First, the dose-response relationship in the Standard is used to determine the probability that a single event will produce an awakening. Then, this probability is converted into a probability of NOT being awakened (1 minus the probability of being awakened). Next, the probability of NOT being awakened all night by multiple events is computed as the joint probability of not being awakened by any of the nighttime events. Finally,

[3] The material presented here on the current ANSI sleep disturbance Standard in the U.S. was provided by Paul Schomer, based on the article, "How Many People will be Awakened by Noise Tonight" by P. D. Schomer and N. P. Miller, *Acoustics Today*, **5**(2), April 2009, pp. 26-31, and the earlier publication by Anderson and Miller in 2007 [15] and ANSI/ASA S12.9/Part 6-2008 [13].

the probability of being awakened at least once by any of the night time events is one minus the joint probability of not being awakened at all. Eq. (1) expresses this approach.

$$\begin{aligned} p_{awake\ once,\ multiple} &= 1 - p_{sleep\ thru,multiple} \\ &= 1 - \prod_{a=1}^{N} \left(p_{sleep\ thru,single} \right)_a \\ &= 1 - \prod_{a=1}^{N} \left(1 - p_{awake,single} \right)_a , \end{aligned} \qquad \text{Eq. (1)}$$

Where:

a = index across all N noise events during the night, and

$p_{awake,single}$ is the probability of being awakened by the ath single event.

Given the probability of awakening an average person by a single noise event, then application of this method for multiple noise events (all with the same sound exposure level) gives Figure B7, which shows the probability of awakening when this average person is subjected to multiple, like noise events during the night. One of the most interesting features to Figure B7 is its marked departure from an "equal-energy" model. For example, 1 event at an SEL of 89 dB predicts a 5% probability that a given individual will be awakened. For this same individual, a 5% probability of being awakened at least once by 5 like events occurs when the DNL equals 52 dB. The ratio of 5 to 1 in number of events is a 7 dB shift in energy, but the corresponding change in SEL is 37 dB.

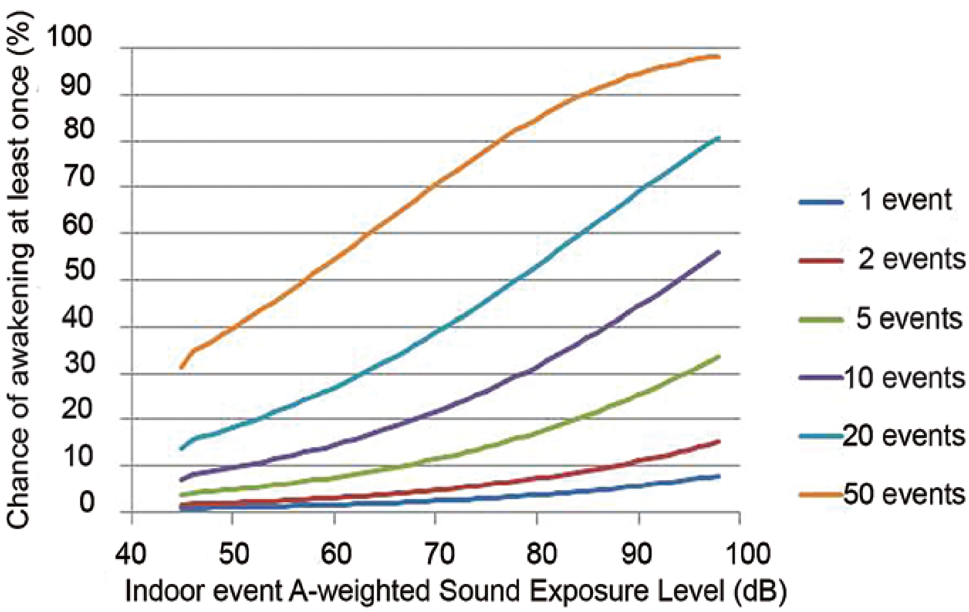

Figure B7. Chance of being awakened at least once versus event SEL for multiple, like noise events

Similarly, yielding the same 40% probability of being awakened at least once are:

(1) 10 like events at 89 dB; (2) 20 like events at 73 dB; and 50 like events at 52 dB. So a doubling in number (20/10), which implies 3 dB, associates with a 16dB change in level, and a ratio equal to (50/20), which implies 4 dB, associates with a 21 dB change in level. Adding these latter two together indicates that a ratio of (50/10), which implies 7 dB, again, just as above, associates with a 37 dB change in level.

Figure B7 clearly does not represent an equal energy relation; a 3 dB change for number of events equates to an 18.3 dB change in level. But the results shown in this figure might be indicating something more like "an equal loudness relation;" a relation where a halving of number of a events (3 dB) relates to a doubling of subjective loudness in sones, which is well known to be a change of about 10 dB in level.

Anderson and Miller actually developed three different levels of prediction of behavioral awakenings, and the Standard uses the first two of these: (1) behavioral awakenings based solely on SEL, and (2) behavioral awakenings based on SEL and *time since retiring.* They apply logistic regression to raw awakening data so that more variables may be included in the dose-response curves. By examining available data on a single subject basis, their regression analysis is able to include not only SEL, but also *time since retiring*. Their results for the two levels of prediction are given by Eqs. (2) and (3), using the equation coefficients given in Table BI.

$$p_{awake,single} = \frac{1}{1+e^{-Z}} \qquad \text{Eq. (2)}$$

and

$$Z = \beta_0 + \beta_L L_{AE} + \beta_T T_{retire} \qquad \text{Eq. (3)}$$

and

$\beta_0, \beta_L, \beta_T$ = Constants (see Table B1)

L_{AE} = Indoor SEL

T_{retire} = Time since retiring (minutes)

Table B1. Values of Eq. (3) constants for the two relationships used to compute awakenings

Awakening Dose-Response Relationships	β_0	β_L	β_T
ANSI (SEL only)	-6.8884	0.04444	0
ANSI (SEL and *time since retiring*[minutes])	-7.594	0.04444	0.00336

As another example, awakenings are computed at a single point based on a real, measured distribution of aircraft A-weighted SEL values, three different nighttime temporal distributions of these aircraft noise events (Table B2), and an assumed outdoor-to-indoor noise reduction of 23 dB. For purposes of this example, the events in Table B2 are grouped into thirds of the night.

Table B2. Assumed distributions of nighttime noise events

Noise Events by Time Period Indicated			
Hours:	Distribution #1	Distribution #2	Distribution #3
10 pm to 1 am	20	35	20
1 am to 4 am	5	5	5
4 am to 7 am	20	20	35
Total	45	60	60

These results are shown in Figure B8, which gives the percent of the population awakened at least once for each scenario. The results for the two different relationships, with or without the factor for *time since retiring*, demonstrate some expected trends. Both relationships show increased awakenings with increased operations, except that, as expected, the relationship based only on SEL *only* shows no difference between distributions #2 and #3, because both have the same number of operations, but at different times of night. Notably, the relationship based on SEL and *time since retiring* systematically shows higher rates of awakening. This occurs because of the non-uniform distributions during the 3 time periods coupled with the large increase in probability of awakening during the early morning hours as compared to other times during the night. This trend is most pronounced for Distribution #3, which has 35 operations during the early morning hours as compared with 20 operations during the early morning hours for Distributions #1 and #2. This figure demonstrates the information lost by an equal-energy type of prediction (SEL *only*) compared to the non-equal-energy prediction that includes *time since retiring*.

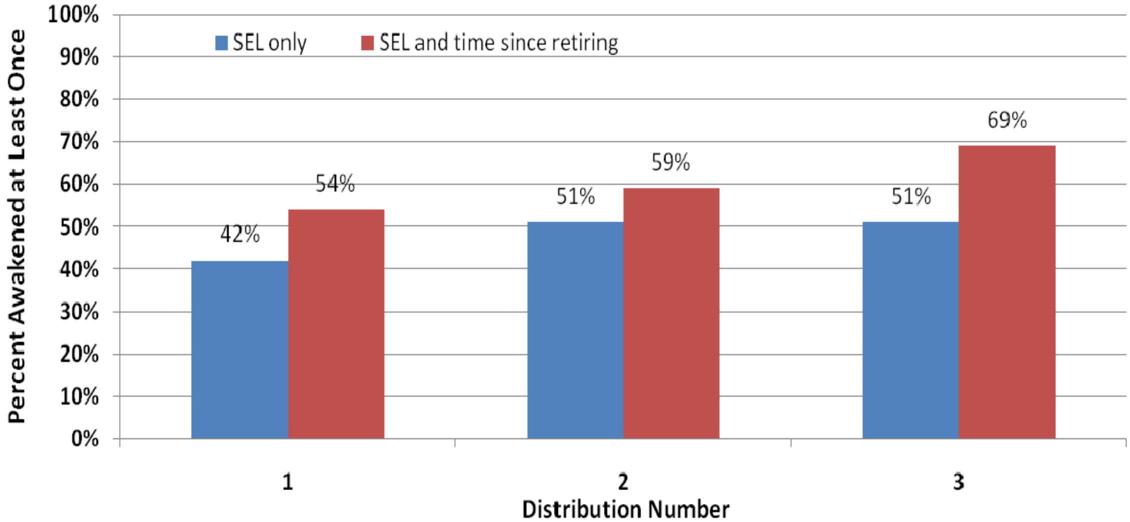

Figure B8. Results for the 3 night time temporal distributions

In conclusion, the method provides a pragmatic general means for estimating the awakening effects of night time noise events. The examples demonstrate the ease of making predictions and illustrate typical relative differences that can be expected between the two relationships. These examples clearly show the non-equal-energy nature of these predictions.

The two relationships produce roughly similar results. However, the relationship that uses only the indoor SEL as a variable obviously shows no time-of-night effect – an effect that was strongly indicated ($p < 0.01$) in the regression analysis of Anderson and Miller, and has been observed by others, e.g., Brink *et al.* [24]. This phenomenon may be important in assessing the effects likely to occur if and when night time noise events become more prevalent.

C. Non-Auditory Physiological Heath Effects

Community noise, such as that from transportation noise sources, industry and construction noise, is considered as a stressor that affects the autonomic nervous system and the endocrine system. Under conditions of chronic noise stress the cardiovascular system may adversely be affected. Epidemiological noise studies regarding the relationship between aircraft noise and cardiovascular effects have been carried out in adults as well as in children and focus primarily on mean blood pressure, hypertension and ischemic heart diseases as cardiovascular endpoints. Evidence ion an increased the risk of ischemic heart disease, including myocardial infarction, is primarily based on road traffic studies. Large scale prospective epidemiological studies on the effect of aircraft noise, including clinical measures of cardiovascular outcomes, are still missing. However there is sufficient evidence that aircraft noise increases the risk of hypertension. Results regarding the effects of aircraft noise on children's blood pressure are still inconsistent, due to methodological reasons.

Based on existing literature it can be concluded that there is sufficient evidence for a positive relationship between aircraft noise and high blood pressure and the use of cardiovascular medication. However, no single common exposure-response relationship can be established for the association between aircraft noise and cardiovascular risk due to methodological differences between studies and the lack of continuous or semi-continuous (multi-categorical) noise data. For the same reason no answer can be given yet regarding possible effect thresholds. Road traffic noise studies suggest that the cardiovascular risk increases when the outdoor noise level during the day exceeds 60-65 dB(A) and 50-55 dB(A) during the night, respectively. As to whether this information can be applied to aircraft noise remains unclear. However based on annoyance studies the effect of aircraft noise might even be stronger than those of road traffic noise. Annoyance studies around major airports show that aircraft noise is perceived as more annoying than road traffic noise of the same average noise level [25, 26]. Recent aircraft noise studies suggest that the risk may increase at even lower night noise levels. Depending on whether high blood pressure was assessed by a self-administered postal questionnaire or by clinical measurements, the magnitudes and the possible thresholds of effect varied between and within studies [27, 28]. Effects were more pronounced, when *subjective* measurements of high blood pressure were considered. This raises questions regarding over-reporting [27, 28, 29]. The validity of study results appears to be even more a problem when subjective noise annoyance was considered as a proxy for exposure [27, 28, 30, 31]. The effect estimates tend to be larger but may be prone to over-reporting, particularly in cross-sectional studies where both, exposure and outcome, are assessed on a self-reported basis within the same questionnaire.

The available results do not allow for a distinction between the sexes: males have been studied much more often than females. Due to the use of different noise indicators in aircraft noise studies only very crude comparisons can be made between studies on the basis of common noise indicators, e. g. L_{dn} or $L_{Aeq,6\text{-}22hr}$. Most aircraft noise studies did not distinguish between day and the night. One study suggests not only that noise during the night may be the primary source of adverse effects; it also shows that within the night period, effects due to noise in the early morning shoulder hours may be larger [32]. However, no firm conclusions can be drawn about the relative contribution of day and night exposure, indices of which are in the case of aircraft exposure, usually highly correlated.

The contribution of noise on children's blood pressure is still not fully understood. Predispositional and lifestyle factors seem to dominate and it is hard to study the influence of environmental noise separate from these. This might be one of the reasons why conclusions about the effect of noise exposure on children's blood pressure are limited and inconsistent. Methodological problems which arise are study size, insufficient contrast between noise levels, selection bias and insufficient adjustment for factors such as SES, parental history, noise insulation and ethnicity. Moreover, most studies on cardiovascular effects in children have focused on school exposure while at least the combination of day- and night time exposure (= school and home exposure) and the related lack of restoration of day time exposure, is an importance to address in studies into the development of cardiovascular disease due to early childhood blood pressure changes.

In a summary of the cardiovascular effects of exposure to aircraft noise developed by Babisch and van Kamp [33] for the October 2007 WHO Workshop on Aircraft Noise and Health in Bonn, Germany, only those studies were considered in which aircraft noise was the explicit noise source. The results of this analysis are shown in Figure B9, below. However, in a situation where sufficient source information is lacking, the results of studies on the association between road traffic noise and myocardial infarction may also serve as an approximation for possible effects of aircraft noise and efforts related to the WHO projects on 'Nighttime Noise Guidelines' [34] and the 'Environmental Burden of Disease' (see http://www.euro.who.int/Noise/activities/20021203_3), which is undergoing review for publication. However, there is a possibility that this may be an overly conservative approach.

Most of the relevant studies reviewed by Babisch and van Kamp [33] used some form of LEQ-based metric, using a 24-hour time base, such as DNL. The major contention is whether there should be a nighttime exposure penalty or not, but the existing literature is not conclusive on this issue. Thus, L_{Aeq24}, DNL and DENL are available for use. However, scientific concern about the additional sensitivity of evening and nighttime responses generally leads towards the increasing use of either L_{Aeq24} or a combination of a daytime LEQ (L_{Aeq16}) and a nighttime LEQ (L_{Aeq8}) as the recommended metrics for aircraft noise impact assessment purposes.

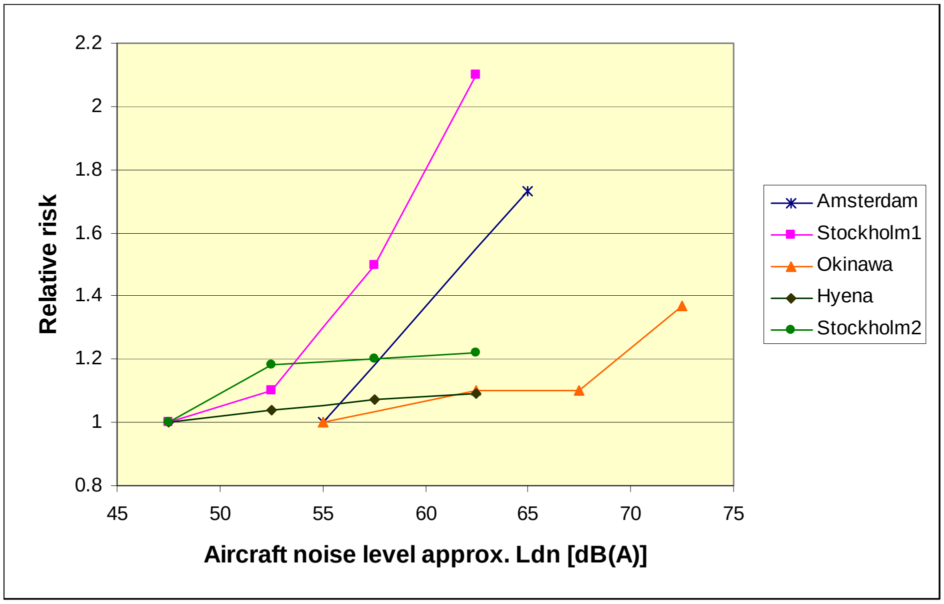

Figure B9. Association between aircraft noise level and the prevalence of hypertension [33].

D. Benchmark Criteria

Making use of the scientific data on topics such as community annoyance, sleep disturbance, and other noise effects, guidelines on community noise exposure criteria have been promulgated internationally to suggest goals and to assist agencies with assessment processes. The World Health Organization (WHO) “Guidelines for Community Noise” [35] is one such set of guidelines. The guidelines for environmental noise have been extracted from the table in the WHO document and are shown in Table B3. These have quickly become acknowledged worldwide, as the goals authorities should aim for community noise criteria. It is important to note that these guidelines include context so that the goals are lower for the more noise sensitive spaces, such as bedrooms. The goals are also lower at nighttime to avoid sleep disturbance.

Table B3: Guideline values for community noise in specific environments (extracted from Table 4.1 in WHO “Guidelines” [35]. The time base for the LAeq value varies as shown in the table).

Specific environment	**Critical health effect(s)**	**L_{Aeq} [dB]**	**Time base [hours]**	**$L_{Amax, fast}$ [dB]**
Outdoor living area	Serious annoyance, daytime and evening Moderate annoyance, daytime and evening	55 50	16 16	- -
Dwelling, indoors Inside bedrooms	Speech intelligibility and moderate annoyance, daytime and evening Sleep disturbance, night-time	35 30	16 8	 45
Outside bedrooms	Sleep disturbance, window open (outdoor values)	45	8	60
School class rooms and pre-schools, indoors	Speech intelligibility, disturbance of information extraction, message communication	35	during class	-
Pre-school bedrooms, indoors	Sleep disturbance	30	sleeping-time	45
School, playground outdoor	Annoyance (external source)	55	during play	-
Hospital, ward rooms, indoors	Sleep disturbance, night-time Sleep disturbance, daytime and evenings	30 30	8 16	40 -

Hospitals, treatment rooms, indoors	Interference with rest and recovery	#1		
Outdoors in parkland and conservation areas	Disruption of tranquility	#2		

#1: as low as practically possible;
#2: existing quiet outdoor areas should be preserved and the ratio of intruding noise to natural background sound should be kept low;

It should be noted that in practice both serious and moderate annoyance can arise at much lower sound levels, depending on the context in which the noise is heard. In addition, there are very many situations in which outdoor 16-hour average, A-weighted sound levels exceeding 55 dB do not cause either serious or moderate annoyance. For these reasons and others, the various WHO guideline values might be better considered as strategic aspirations. For what are usually sound practical reasons, much higher benchmarks for time-averaged, A-weighted sound levels typically in the range between 65 dB and 70 dB are normally adopted for regulatory purposes, or for other purposes such as defining statutory entitlement to additional noise insulation. It should be noted, however, that exposure criteria adopted for regulatory purposes are almost always higher than those found in published exposure guidelines. The guideline values represent ideal goals for exposure to noise, while regulatory values are subject to legal action if not complied with. For example, when agreeing on exposure benchmarks, regulatory authorities need to consider the relative costs of compliance where the benchmark is set either up or down as compared to the anticipated benefits, as well as the technological feasibility of achieving particular exposure criteria. To cite on example, for most developed nations, setting environmental ambient noise benchmarks as low as a time-average, A-weighted sound level of 55 dB, while it is a worthwhile goal, is often not realistic as there is very little possibility of compliance within either the short or medium term future. It must be pointed out that I-INCE is not in a position to recommend either guideline or regulatory exposure criteria. The current report simply presents values provided by other organizations, such as WHO, and recognition of current practices in various countries.

Authorities can use published guidelines along with other factors associated with their particular region, including data on the existing background noise levels, to establish area specific ‘acceptability’ criteria. Such an approach is administratively convenient; in particular as assessing the noise impact becomes simply a matter of comparing the predicted noise levels with these criteria. It also appears to provide equity if the same criteria are applicable to all jurisdictions within the region.

However, in reality, this is not the case. As discussed above the reactions to noise is not a simple relationship. People who feel adversely affected by noise do not appreciate being told that they do not count because their exposure is below some fixed criterion level. Others who are less sensitive to community noise might feel the benefits to the community of a proposal compensate for a slightly higher noise level. Also those less sensitive to noise may be annoyed by the introduction of noise mitigation such as large barriers.

Each country can adopt its own criteria, or use international recommendations. It is important that, when a community noise impact assessment is conducted, the criteria used are valid, defendable and traceable.

Noise level goals and area specific criteria both have a role in providing guidance to the authorities for assessment of noise impact from a proposed development project. However, it is important that the variability in the reactions within and between communities be acknowledged and flexibility in the application of such criteria be considered in the impact assessment. It should not be a bureaucratic approach where the assessment of the noise impact is simply a comparison between the predicted noise levels and defined criteria. The process of the noise impact assessment should aim to achieve the best negotiated outcome for all those involved, as described in the body of this report.

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