The status of international guidance and standards for environmental noise assessment

Douglas Manvell 1
DMdB
Teglgaardsvej 52, Charlottenlund, Denmark

ABSTRACT
Since its first publication in 1971 of ISO/R 1996:1971 on Acoustics Assessment of Noise with Respect to Community Response, the International Organization for Standardization (ISO) has developed and published a range of standards for environmental noise assessment. The main ISO 1996 series of standards on Description, Measurement and Assessment of Environmental Noise has been developed in phases. And almost 30 years ago, ISO 9613 Attenuation of Sound During Propagation Outdoors was added. More recently, supporting standards such as the ISO PAS 20065 Objective Method for Assessing the Audibility of Tones in Noise and the ISO 17534 series concerning Software for the Calculation of Sound Outdoors have been added, and cooperation initiated with the International Electrotechnical Commission on the IEC 61400-11-2 Assessment of Wind Turbines Noise at receptor positions.

This paper provides an overview of ISO standards related to environmental noise assessment. It also describes the historical development of the ISO 1996 series and related standards. Current developments, including their status, are described. Finally, it provides some suggestions and considerations for further research.

1. INTRODUCTION
The International Organization for Standardization (ISO) has developed and published a range of standards for environmental noise assessment. The main ISO 1996 series of standards on Description, Measurement and Assessment of Environmental Noise has been developed over a period of 50 years. During this period, additional ISO standards have been published on related topics including sound propagation outdoors and the implementation of these standards in software, and specific methodology for assessing tonal and impulsive sources. Cooperation has also started with the International Electrotechnical Commission concerning the assessment at receptor positions of wind turbines.

Excluded from the overview in this paper are the ISO standards concerning aircraft noise monitoring at receptor positions, indoor noise assessment of insulation of traffic noise, assessment of individual sources and of noise barriers. Also excluded are other international standards such as ISEE blasting and national or regional standards as produced by BSI, DIN, AFNOR, etc or in European Union funded projects such as Harmoise/Imagine and CNOSSOS-EU.

2. HISTORICAL REVIEW
2.1. ISO 1996 Environmental Noise Assessment
The development of the ISO 1996 series can be divided into 4 phases:

1 douglas.manvell@dmdbsoundadvice.com
2. Creating an actual standard – the 1980s
4. Adding guidance and refining - since 2010

Phase 1, Gathering Experience - ISO/R 1996:1971

The first standard developed by the International Organization for Standardization (ISO) was a recommendation, ISO/R 1996, published in 1971 (1) on Acoustics Assessment of Noise with Respect to Community Response, and only 10 pages long. Although it was written prior to the development of sound level meters able to directly measure average-energy levels (see below), an adjusted $L_{Aeq}$ called the Rating Sound Level, now called the Rating Level, was introduced as the primary parameter to be used to determine community response. Determining $L_{Aeq}$ was either based on measurement of a steady state situation or based on statistics gathered and processed by advanced systems. Noise limits were proposed for different land use zones, day, evening and night adjustments were introduced although the night period had an adjustment of 10-15 dB, and tones and impulses were adjusted by 5dB. Assessment through the use of exceedence/emergence of specific sound above the background noise level, defined as the $L_{95}$, was promoted for some situations.

Phase 2, Creating an Actual Standard - ISO 1996 in the 1980s

During the 1980’s, ISO 1996 was developed into a full standard consisting of:

- ISO 1996-1:1982 (2), Basic quantities and procedures, 5 pages
- ISO 1996-2:1987 (3), Acquisition of data pertinent to land use, 7 pages
- ISO 1996-3: 1987 (4), Application to noise limits, 3 pages

With the introduction of the world’s first handheld sound level meter to provide integrated $L_{eq}$ and sound exposure level (SEL) measurements in 1980 (5), measuring $L_{Aeq}$ became significantly easier, and integrating-averaging sound level meters were internationally standardised in IEC 804:1985 (6). There were still challenges but this was a significant step.

This series aimed at providing authorities with material for the description of noise in community environments, to enable acceptable limits of noise to be specified, and compliance with these limits controlled. Up to and around this time, national methods for specific sources were becoming more widespread. For example, in Denmark, the EPA had published industrial noise guideline in 1974. Thus, with the development of noise limits in national legislation, and in line with a strategy where legislation defines the limits while standards define how to assess what the actual limit or level is, the recommended adjustments for different land use zones were removed. Here, the concept, now almost universal, of assessing noise from a specific source was introduced. Although there was limited development, with the standard only growing slightly, there were some important developments.

In Part 1, the concepts of specific noise and reference time durations were defined. Importantly, measurement positions near buildings were added, as was enhanced guidance on dealing with fluctuating noise. Part 2 covered Rating Level and adjustments for acoustic content, meteorology, and the application to long term periods. Here, significant practical guidance on measurements compared to the 1971 edition was added. As noise calculation standards were beginning to be published in the late 1970s and 1980s, eg VDI 2714, CONCAWE and CRTN, the use of prediction was introduced and how noise zones (filled contours) should be presented was standardized. Part 3 provided guidance on setting noise limits including relevant time intervals, source operating conditions, locations and meteorological conditions.
Phase 3, Updating and Detailing - ISO 1996 from 1996 to 2007

After the TC 43/SC 1 plenary meeting in South Africa in 1996, Working Group 45 of ISO Sub Committee on Noise, of which the author is now convenor, was formed to revise the entire ISO 1996 series. At the same time, the EU Green Paper on Future Noise Policy (7), a significant milestone in environmental noise control, was published in 1996, consolidating the $L_{DEN}$ and the nighttime $L_{Aeq}$, $L_{Night}$, as the primary strategic parameters for environmental noise management. The following publications are part of this phase:

- ISO 1996-1:2003 (9) – grown to 34 pages

With the wide variety of sources and socio-economic conditions around the world, and with national assessment methods, typically developed in relative isolation and strongly embedded in national legislation, ISO 1996 focused on ensuring general good practice and helping emerging nations develop quality noise assessment legislation and standards. Despite the variability of national assessment methods for specific sources and conditions, the series was successful in gathering and getting agreement on good practice that is globally applicable, and the principles remain almost fully global.

The first action was to amend the ISO 1996-2:1987. AMD 1:1998 primarily updated the adjustments to be added for impulsive character to sound based on major research, categorizing the sources into highly, high-energy and ordinary impulsive sounds, pre-empting the next edition of the standard.

After that, a full revision and expansion of the series was initiated, resulting in these editions being significant developed and totally reorganized.

The 2003 edition of Part 1 defined descriptors for environmental noise for single events, repetitive single events and continuous sound. The main focus was on long-term community annoyance response, and rating levels were supplemented with composite whole-day rating levels such as $L_{DEN}$ and $L_{DN}$. Instead of noise limits, requirements to the setting of noise limits were defined. The estimated percentage of a population highly annoyed as a function of adjusted day/night sound levels, also known as the dose-response curves, were introduced as well as guidance on annoyance caused by exposure to sound in multi-source environments. The so-called Schultz curve was updated based on the independent researches of Miedema and Finegold. Adjustments for sound source rating levels were updated according to the latest research. And how to deal with high-energy impulse sounds and sounds with strong low-frequency content were covered in informative annexes.

The 2007 edition of Part 2 developed significant additional guidance to meet the need to determine long term levels. In addition, as part of ISO Acoustics strategy, measurement uncertainty was introduced, covering uncertainties due to the instrument and operator, weather, source operation and the influence of the newly defined parameter, residual sound (see below). Requirements for instrumentation and its calibration were updated, and aspects concerning operation of the source and its representativity for determining long-term levels were documented. Despite the focus on long-term levels, the standard is also applicable for short term use. Specific guidance on roads, railways, aircraft, industrial plants and low-frequency sound sources were provided. Weather conditions were defined including those conditions favourable to sound propagation (the meteo window), and guidance on determining the average sound pressure levels under a range of weather conditions was added. The measurement procedure included selection of the measurement time interval, and guidance concerning the microphone location and the comparison of results to the reference conditions (eg the incident free-field). Guidance on the evaluation of the measurement result was provided. This edition introduced the residual sound parameter, defined as all sound not belonging to the specific source under
investigation and thus different to the LN-defined background noise level. Extrapolation to other conditions such as location, other time and operating conditions was also covered. Calculation referred to existing source-specific methods. Information to be recorded and reported was updated. An objective reference method for assessing the audibility of tones in noise, based on narrow band analysis was defined, and the existing 1/3-octave objective method was updated such that tone detection based on the difference to the neighbouring bands now varied with frequency.

Phase 4, Adding Guidance and Refining - ISO 1996 since 2010

With the introduction of dose-response curves in ISO 1996 and the increasing amount of research, significantly assisted by the new results from the European Union’s strategic noise maps due to the European Noise Directive 2002/49/EC, it was natural that Part 1 be revised to accommodate recent experience and new developments. In addition, a need for additional guidance on determining the uncertainty of the assessment was identified. Work was immediately initiated and resulted in:

- ISO 1996-1:2016 (11) – further expanded to over 50 pages
- ISO 1996-2:2017 (12) – grown to 68 pages

The significant expansion of Part 1 was due to added detail on the estimation of the long-term annoyance response of communities, the variation in response, not only from one source to another, but also its development over time, as well as the variation of response from one community to another, quantified by the use of the Community Tolerance Index. Annoyance curves were now also presented for LDEN as well as for LDN. Other refinements and clarifications were also added to provide further guidance on determining the long-term rating level.

In addition to significant additional and more robust guidance on uncertainty assessment, including worked examples to help users, Part 2 was reorganized and updated with additional detailing and guidance to ease its use. This included revised guidance for determining weather conditions and their impact, and the radius of curvature of the sound paths was introduced. More detail on the selection of the measurement site and correction of levels to reference conditions was provided. Elimination of unwanted sound, how to deal with maximum sound pressure levels in regulations, and the measurement of residual sound were all detailed. For assessing the audibility of tones, the engineering (reference) method was removed from Part 2 and, instead, ISO PAS 20065 (13) was developed (see below) and referred to. During revision, there were requests for more intuitive guidance for assessment of the main specific sources in order to make the standard more practically oriented as well as making it more accessible for the general user. This was not significantly addressed in this revision.

2.3. Environmental Noise Calculation, ISO 9613 and ISO 17534, in 20 year steps

Moving onto noise calculation, almost 30 years ago, ISO 9613 Attenuation of Sound During Propagation Outdoors was published. And, more recently, the ISO 17534 series concerning Software for the Calculation of Sound Outdoors has been added.

ISO 9613 Part 1 (14), calculation of the absorption of sound by the atmosphere, was first published in 1993 and in 1996, ISO 9613 Part 2 (15), the general method of calculation. Both remain in force, unchanged for now (however, see below). ISO 9613 is widely used around the world with Part 2 mainly applied to industrial sources while roads, railways and aircraft have developed and are used as industry or national/regional methods.

Some 30 years later, The ISO 17534 series on quality assurance of the implementation of methods for the calculation of sound outdoors in software was initiated in the 2010s. Part 1 (16), the general requirements for how to setup test cases, perform testing and document compliance, was published in 2015. And, the same year, ISO/TR 17534-3:2015 (17) covering the implementation of
ISO 9613-2 in software, was published as a technical report. This included agreement on how to interpret unclear sections of ISO 9613. Additional work on other parts of this series relating to the quality assurance of calculation methods not published by ISO is outside the scope of this paper.

3. CURRENT WORK

Currently, there are 4 work items within ISO on environmental noise within this paper’s scope:

- ISO 1996-1, quantities and assessment procedures: revision initiated
- ISO PAS 1996-3, impulses: close to publication
- ISO TS 20065, tones: nearing completion
- ISO 9613-2, calculation: 1996: under revision

In addition, the ISO Working Group 45 has set up a liaison with IEC PT 61400-11-2 wind energy generation systems and the measurement of wind turbine noise characteristics in receptor positions.

3.1. ISO 1996-1 Quantities and Assessment Procedures

A minor revision of this standard has been initiated. As a preliminary work item, there is no formal deadline for completion of this work. Although it is not yet possible to describe what the changes will be, it is expected that there will be editorial changes to make the standard easier to use by providing better overview and cross-references. There are also requests to look at other effects of noise than annoyance such as IHD and sleep disturbance. And the working group has initiated work to get better insight into recent developments and research to enable development of the standard at a later date. This could include other impacts than annoyance, further insight into geographical regional variation, etc (see also below).

3.2. ISO PAS 1996-3 Impulses

An adjustment is added to the measured $L_{Aeq}$ if prominent impulsive sound is present. In ISO 1996, three categories of impulsive sound have been found to correlate best with community response, and adjustments are given for each. However, the list of impulsive sound sources in each category is incomplete. So, ISO PAS 1996-3 (18), based on Nordtest Acou 112 (19), was initiated to objectively measure the prominence of impulsive sound relative to residual sound. The resulting adjustments can be applied directly or may be used to categorize the impulsive sources. It complements the ISO 1996-2 general purpose environmental noise measurement method. It is due for publication this year and more details of the method can be found in a Euronoise 2021 paper by Manvell & Pedersen (20).

3.3. ISO TS 20065 Tones

ISO TS 20065 Objective Method for Assessing the Audibility of Tones in Noise is an upgrade of the standard from a Publicly Available Specification from 2016 to a Technical Specification, TS. A TS is intended as a precursor to later publication as a full International Standard and, unlike a Publicly Available Specification, does not have a maximum life. In addition to its conversion, the changes were primarily editorial and intended to provide a clearer standard, additional background information, and to include audio files to help the implementation of software. At the time of writing, the Draft Technical Standard is now out for voting. If accepted, it is expected published at the end of this year.
3.4. Revision ISO 9613-2 Calculation

ISO 9613-2:1996 is also under revision with publication targeted in early 2023. A Committee Draft has just been distributed for comments and voting so it is not possible to describe with certainty what the changes will be. However, it was intended to incorporate the clarifications on how to interpret unclear sections of ISO 9613 that are published in the ISO 17534-3 quality assurance standard and, based on feedback, describe how to use it for calculation of noise from wind turbines. In addition, other aspects including dealing with extended sources, higher-order multiple reflections, vertical cylindrical surfaces and meteorology are under development and discussion, and may be included.

3.5. IEC PT 61400-11-2 Wind Turbines

After phase 3 of the development of the ISO 1996 series, ISO Working Group 45 decided to start work on a standard concerning measuring noise from wind turbines at traditional noise assessment positions as there was a growing request for guidance on this method, as opposed to measuring sound emission levels and extrapolating levels to distant receiver positions. The same request was brought to the International Electrotechnical Commission (IEC) working group on wind turbine noise and, as with resources and expertise available in that group, a common strategy was agreed upon where the IEC working group would develop the method with assistance from ISO Working Group 45. ISO strategy is, through liaison and review, to enable the resulting standard to be accepted, used and referred to, thus meeting ISO’s needs and ensuring common standardization. Liaison was set up at the start of this IEC development and the preliminary results have been successful. Publication as a Committee Draft is expected soon.

4. CONSIDERATIONS FOR THE FUTURE

Based on experience and maturing assessment methodology over recent years, the following suggestions for further research and development of new and improved standards are proposed discussed within the relevant ISO working groups and ISO’s Acoustics technical committee management.

- Basic quantities and dose-response relationships: ISO 1996 Part 1
- Assessment of levels: ISO 1996 Part 2
- Tone detection
- Noise calculation methodology
- Long-term monitoring
- Impulse detection research


Since its publication, significant research has been undertaken and published, presented and discussed at several international conferences. Some examples include the WHO Noise in Europe report from 2018 (21) and the US FAA’s Towards A Quieter Americas project (22). At a keynote lecture on new evidence from ICBEN at Internoise 2020, Irene van Irene van Kamp described the status:

- Exposure effect relations are available to relate noise exposure ($L_{den}$ and $L_{Night}$) for % highly sleep disturbed, the % Highly Annoyed, incidence and mortality due to coronary heart disease and cognitive effects.
- Evidence exists regarding noise from different modes transport, industries, neighbours and building services and may also be available for annoyance due to construction noise.
- More research is needed on the increasingly important areas ventilation systems, heat pumps, wind turbines and cooling systems
Some countries in Europe, for example, Denmark, the Netherlands and Switzerland, have begun to review their noise limits based on updated and new dose-response curves.

The current edition of ISO 1996-1 focusses on annoyance and describes the Community Tolerance Index to help determine local differences. However, Working Group 45 has begun to discuss whether other effects of noise such as sleep disturbance, IHD, diabetes and cardiovascular disease should be added, and guidance on determining noise limits updated to potentially migrate policy to one based on harm as well as annoyance. Thus, Working Group 45 has initiated getting better insight into recent developments and research to enable development of the standard, probably after the current revision is completed. This could include other impacts than annoyance, further insight into geographical regional variation, temporal shift, the impact of steady contra intermittent sound exposure for similar sources such as different roads, etc. It could also include extending the standard to cover sources such as wind turbines and recreational activities, or adding considerations of cost-benefit.

4.2. Assessment of levels: ISO 1996 Part 2

Despite the variability of national assessment methods for specific sources and conditions, the series was successful in getting agreement on good practice that is globally applicable. However, this resulted in limited specific guidance, proving problematic for some users. Thus, during development of the latest Part 2 revision, there were requests for more intuitive guidance for assessment of the main specific sources, in order to make the standard more practically oriented as well as making it more accessible for the general user. This was not significantly addressed in the latest revision. Development of more detailed, specific guides on dealing with specific sources and particular assessment methods, including help to determine uncertainty, would make the standard more accessible and spread good practice. This could be done as a series of separate Technical Specifications or informative annexes, thus helping ensure widespread support while not being in conflict with existing, robust, national standards. Part 2 does provide some specific guidance on roads, railways, aircraft, industrial plants and low-frequency sound sources but does not do so on wind turbines, recreational noise, shooting ranges, heat pumps, etc. These are important sources and additional clauses in the standard to cover these would be beneficial. Some papers have been written and feedback received on use of the particular aspects of the standard, especially concerning microphone positioning, and this could also be addressed.

4.3. Tone detection

The ISO 20065 tone detection assessment was intended as a precursor to a common ISO method for the determination of the audibility of tones which could be implemented in relevant ISO application-specific standards for environmental noise, office machines, etc. This strategy was formed by the ISO Noise Sub Committee leading up to the publication of ISO 1996-2:2017. The next stage of development of this strategy was deferred until after the revision of ISO 7779:2018 (23) concerning noise from information technology and telecommunications equipment which also requires the detection of tones. A formal proposal to initiate a common ISO method for the determination of the audibility of tones has not yet been received by the ISO Noise Sub Committee but is under discussion.

4.4. Noise calculation methodology

In relatively recent years, noise calculation engineering methods have developed significantly, primarily in Europe and based on propagation theory rather than on empirical studies, first with the
publication of Nord2000, then with further development as Harmonoise and its successor, Imagine. Full exploitation of these methods requires detailed data which is not always widely available, and have a significant additional calculation load compared to previous methods. Thus, subsequently, the concepts in these state-of-the-art engineering methods were made operational for the European Union’s strategic noise mapping in the CNOSSOS-EU method (24). This will be widely used for the first time in this year’s EU strategic noise maps. After that, based on feedback and experience, the CNOSSOS method may become mature for international standardization, potentially as a replacement or revision of ISO 9613-2.

In addition, the ISO 17534 series of quality assurance standards for software for the calculation of sound outdoors, deserves further attention. With a revision of ISO 9613-2:1996 underway, a revision of ISO/TR 17534-3:2015 is due, enabling software suppliers to declare compliance with the revision, and to provide users with assurance that software has correctly implemented the revision.

4.5. Long-term monitoring

ISO currently has a standard for airport noise monitoring, ISO 20906 (25). In addition, ISO 1996 covers general principles of the use of long-term monitoring for environmental noise assessment. Both standards refer to IEC 61672 (26) compliant solutions. Despite the nature of airport noise being different to that in a city, the ISO 20906 standard is often referred to. To my knowledge, only China has a dedicated city-noise monitoring standard. However, the development of Smart cities, digital twins, IoT-based solutions, and MEMS microphones, among other things, has led to a rise of noise monitoring solutions and practice without being able to refer to internationally-agreed best practice nor instrumentation, as IEC 61672 does not permit the certification of systems based solely on MEMS-based microphones, as its test methods require access to the preamplifier input, after the microphone cartridge, which is not possible with MEMS-microphones.

So, as there now has been some experience with Smart cities and IoT-based noise monitors, and with a gap in the standards, the application is ripe for the development of suitable standards. Neither the relevant ISO TC43 SC1 Noise nor the IEC TC29 Electroacoustics committees have ongoing developments in this area at the moment. Therefore, initial discussions on a strategic level between the chairs of ISO Noise TC43 SC1, the author, and IEC Electroacoustics TC29, Richard Barham, have been initiated. Thoughts include the development of:

- A monitoring standard for cities, perhaps partly based on ISO 20906
- Type approval of MEMs-microphone based monitors

Discussions involving more people are encouraged in order to form the basis of a strategy, perhaps both in ISO and in IEC, and to initiate development, perhaps also involving other standardisation bodies covering city furniture, IoT, city planning, etc such as the ISO and IEC Joint Technical Committee on IoT and Digital Twins.

4.6. Impulse detection research

Compared to the amount of research on community annoyance from road traffic, aircraft and rail noise, the amount of research on annoyance from impulsive sound is limited. Therefore, ISO PAS 1996-3 includes an informative annex recommending further research on relevant sources to support its development into a full ISO standard, including:

- The use of sound signals as would be experienced/assessed at large distances; as influenced by propagation; both outdoor- and indoor; with real-world signal to noise ratios;
- The correlation of $k_I$ with Prominence for impulses with very high onset rate;
• The use of a sufficiently large number of participating listening subjects;
• Rating of annoyance based on comparison with equally annoying traffic noise;
• Surveys of real communities exposed to the actual noise source to develop a dose-response relationship, such as those used for adjustments to road rail and aircraft noise, eg CTL
• The statistical relevance of various ways of considering the prominence of impulses in dose response relations

As the Publicly Available Specification will be reviewed 3 years after publication, researchers, cognizant authorities and experienced practitioners are encouraged to use this standard in the coming years to ensure that this review is based on a broad and solid foundation.

5. CONCLUSIONS

This paper provides an overview of the history of ISO environmental noise assessment standards from the first publication in 1971 to today. The main ISO 1996 series of standards on Description, Measurement and Assessment of Environmental Noise has been developed in 4 phases and is now entering a 5th. The first ISO noise calculation standard was published almost 30 years ago and is now being further developed, also regarding quality assurance of software. Additional ISO standards on tone and impulse detection have and are being added. Work is ongoing, also in cooperation with IEC, on a range of standards. The paper concludes with some suggestions and considerations for further development and research – enough for a few more papers from a number of researchers!

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7. REFERENCES

5. "Our History", Cirrus Research (https://www.cirrusresearch.co.uk/about/history/). Retrieved 28th March 2022