Institution:
University of Cambridge

Unit of Assessment:
UoA4

Title of case study:
Measuring loudness: a new international standard with widespread industrial applications

1. Summary of the impact (indicative maximum 100 words)

Loudness is the subjective magnitude of a sound as perceived by human listeners and it plays an important role in many human activities. It is determined jointly by the physical characteristics of a sound and by characteristics of the human auditory system. A model for predicting the loudness of sounds from their physical spectra was developed in the laboratory of Professor Brian Moore with support from an MRC programme grant.

The model formed the basis for an American National Standard and is currently being prepared for adoption as a standard by the International Organization for Standardisation (ISO).

In addition, the model has been widely used in industry worldwide for prediction of the loudness of sounds, for example: noise from heating, ventilation and air-conditioning; inside and outside cars, and from aircraft; and from domestic appliances and machinery.

2. Underpinning research (indicative maximum 500 words)

The auditory perception group is led by Professor Brian Moore (Department of Psychology from 1977; Professor of Auditory Perception from 1995). In the late 1990s, Moore and colleagues (Brian Glasberg and Thomas Baer, each Senior Research Associate) started developing a model in humans for predicting the loudness of sounds based on their physical spectra. This model was based on extensive prior research into human frequency selectivity, which had produced a detailed characterization of human 'auditory filters' and how these vary with frequency and level.

The initial version of the model,[1] published in 1996 was an extension of the earlier 'Zwicker loudness model' (1958), which had until that point been used in many practical acoustical applications. The extension accounted more accurately for the shapes of equal-loudness contours (showing the sound level required for equal loudness of pure tones with different frequencies) and the way that equal-loudness contours change with loudness level, as published in the literature. The model also accurately predicted loudness judgements for a variety of sounds, as obtained in Moore's laboratory and documented in the published literature. In 1997, the model was further altered, developed and refined[2] (the most highly cited paper in the *Journal of the Audio Engineering Society*) and, as a result, became substantially different from the Zwicker model. This version enabled prediction not only of the loudness of sounds, but also of the loudness of a given sound in the presence of background noise. This paper included equal-loudness contours predicted by the model, which differed from the equal-loudness contours that were currently the accepted standard. However, in 2003 a new ISO standard for equal-loudness contours was published, based on new perceptual data collected independently of Moore's group; and these new contours were close to those predicted by the model. During the period 1998-2002, data were gathered on the loudness of time-varying sounds, by Moore's group and by researchers working independently; together, these were used to develop a version of the model that could deal with time-varying sounds.

In 2006, Moore's model was further modified to allow accurate prediction of the detection thresholds of both simple and complex sounds,[3] and in 2007 it was extended to enable accurate predictions of loudness under conditions where the sound is different in the two ears, as is common in everyday life.[4] Moore's model is the only one to include this feature.

In parallel with research on the perception and modelling of loudness for normal hearing, Moore and colleagues have extended the model to predict loudness as perceived by hearing-impaired people[5] (the most highly cited paper in the journal *Auditory Neuroscience*), based on data gathered in Moore's laboratory and by other groups. This version of the model has been used by Moore's group to develop methods for fitting hearing aids with multi-channel compression,[6] which compensate for the effect of loudness recruitment commonly found in people with sensorineural hearing loss.

3. References to the research (indicative maximum of six references)

1. Moore, B. C. J., and Glasberg, B. R. (**1996**). "A revision of Zwicker's loudness model," Acustica -

Acta Acustica **82**, 335-345.

2. Moore, B. C. J., Glasberg, B. R., and Baer, T. (**1997**). "A model for the prediction of thresholds, loudness and partial loudness," J. Audio Eng. Soc. **45**, 224-240.

3. Glasberg, B. R., and Moore, B. C. J. (**2006**). "Prediction of absolute thresholds and equal-loudness contours using a modified loudness model," J. Acoust. Soc. Am. **120**, 585-588.

4. Moore, B. C. J., and Glasberg, B. R. (**2007**). "Modeling binaural loudness," J. Acoust. Soc. Am. **121**, 1604-1612.

5. Moore, B. C. J., and Glasberg, B. R. (**1997**). "A model of loudness perception applied to cochlear hearing loss," Auditory Neurosci. **3**, 289-311.

6. Moore, B. C. J., Glasberg, B. R., and Stone, M. A. (**2010**). "Development of a new method for deriving initial fittings for hearing aids with multi-channel compression: CAMEQ2-HF," Int. J. Audiol. **49**, 216-227.

DETAILS OF MRC programme grants (all with Moore as principal investigator)

1993-1998	Studies of impaired hearing and development and evaluation of signal processing hearing aids. £534870
1998-2003	Studies of normal and impaired hearing and development of digital hearing aids. £1,189,563
2003-2008	Studies of normal and impaired hearing and development and evaluation of signal processing hearing aids. £1,510,000.
2008-2013	Psychoacoustics of normal and impaired hearing and applications to hearing aid design and fitting. £2,067,098.

4. Details of the impact (indicative maximum 750 words)

The version of the model published by Moore’s group for normal hearing was implemented in 2007 in American National Standards Institute (ANSI) standard number ANSI S3.4-2007.[1] As a result, the model is used by companies based in the USA and elsewhere for evaluating the loudness of their products. The model is widely used in industry for prediction of the loudness of everyday sounds such as noise from aircraft, traffic, inside cars, heating and ventilation systems, wind turbines, and many other situations. It has also been used by government organisations.[2]

The Danish company Bruel and Kjaer[3] (a leading manufacturer of sound and vibration measurement equipment) uses the model as part of package of sound-measuring equipment that is widely used in industrial applications. A range of companies, including Boeing,[4] Bose,[5] Samsung,[6] and Nissan[7] use the model, as implemented in a computer program, to assess the loudness of their products, since it eliminates the need to undertake expensive and time-consuming tests with human listeners. The executable code of the model for the loudness of stationary sounds is made available as part of the ANSI S3.4-2007 standard. Companies pay a license fee to use the software for the model of loudness for time-varying sounds.

Examples of applications are:

1) The model has been used by the US Department of Transportation[2] and by Nissan[7] in developing the design and specification of warning sounds to be emitted by quiet cars, such as electric automobiles.

2) The model has been used by Boeing Corporation, a major manufacturer of aircraft, to evaluate the loudness of sounds both inside and outside of aircraft.[4]

3) The model has been used by Bose Corporation, a major manufacturer of audio systems for domestic and professional applications in developing a variety of products.[5]

4) The model has been used by Samsung[7] in a variety of applications including development of more efficient perceptual coders (improvements to MP3) and evaluation of the loudness of mobile

telephones.
5) The version of the model applicable to hearing-impaired people has been used by Moore's group to develop methods for fitting hearing aids with multi-channel compression (essentially all modern hearing aids incorporate such compression). A recent extension to these methods (reference 6 in section 3) can be used to fit recently introduced hearing aids with an extended high-frequency response (i.e. those that amplify for frequencies up to 8-10 kHz as opposed to the limit of 4-5 kHz that is common for hearing aids). This method, called CAM2, is currently being used in clinical trials with a novel form of hearing aid with extended high-frequency response, called the 'Earlens'. The trials are being conducted in Stanford, USA, with Moore as advisor. The CAM2 method is currently being licensed by Cambridge Enterprise.[8]
The model is being adapted as the basis for a new ISO standard. Voting on the proposed standard should take place later on this year. The new standard will be published in parallel with a revised version of a standard based on the older (and less accurate) Zwicker model for a limited period.

5. Sources to corroborate the impact (indicative maximum of 10 references)

1. The ANSI standard explicitly includes a statement that it is based on the Moore/Glasberg loudness model:

ANSI, 2007. ANSI S3.4-2007. Procedure for the computation of loudness of steady sounds, American National Standards Institute, New York.

2. Hastings, A., Pollard, J. K., Garay-Vega, L., Stearns, M. D., & Guthy, C. (2011, October). Quieter Cars and the Safety of Blind Pedestrians, Phase 2: Development of Potential Specifications for Vehicle Countermeasure *Sounds.* (Report No. DOT HS 811 496). Washington, DC: National Highway Traffic Safety Administration.

This document describes use of the Moore/Glasberg loudness model in developing the specifications for quiet vehicles. This document has been uploaded to the repository. It can be accessed at:
http://www.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2011/811496.pdf

Supporting documents in the repository have been provided by:

3. Research Engineer at Bruel and Kjaer (Denmark), a leading manufacturer of equipment for acoustical measurements and calibration.

4. Manager, Acoustics Technology, Noise, Vibration and Emissions Engineering, Boeing Corporation, a major aircraft manufacturer.

5. Manager, Acoustic Research, Bose Corporation (U.S.A.), a leading manufacturer of loudspeakers and sound systems.

6. Manager, Market Quality Engineering, Nissan Corporation, a major manufacturer of motor vehicles, including electric cars.

7. Principal Engineer, Digital Media & Communication R&D Center, Samsung Electronics, a major manufacturer of mobile telephones, electronic equipment, and appliances.

8. A web site describing the CAM2 software and its uses and licensing opportunities is:
http://www.enterprise.cam.ac.uk/industry/licensing-opportunities/cam2-software-hearing-aid-fitting/