A REVIEW OF RESEARCH INTO HUMAN RESPONSE TO THE AMPLITUDE MODULATED COMPONENT ON WIND TURBINE NOISE AND DEVELOPMENT OF A PLANNING CONTROL METHOD FOR IMPLEMENTATION IN THE UK

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1 INTRODUCTION

In wind turbine noise (WTN), continuous modulation of the amplitude envelope occurs during rotor revolution, producing sounds commonly described as 'swish', or sometimes as 'thump'[1]. As has been highlighted, amplitude modulation (AM) of WTN is an important factor in determining the subjective response[2, 3]. Industry and public concern about WTN AM has been growing in the UK over recent years, although the extent of the issue is not fully understood.

A recent study of wind farm impacts in Scotland indicated that AM could be perceived by residents in around two thirds of the ten case study sites, however specifics about the AM (such as the magnitude) were less clear[4]. The study also noted that a large majority of the surveyed residents were not affected by noise from the wind farms. A national survey of noise attitudes (SoNA) and annoyance in the UK has recently been published[5]; the fact that wind farm noise does not feature in the key findings may reflect the relatively small proportion of the UK population exposed to WTN. Nonetheless, wind farm noise can be a significant and highly emotive issue for those involved[6, 7, 8], and has been shown to induce greater annoyance in individuals compared with other environmental noises[9].

Existing planning policy in the UK refers to the ETSU-R-97 guidance for assessment of the potential noise impact of new wind farms[10]. The approach in this document is supplemented by a Good Practice Guide[11] published by the UK Institute of Acoustics (IOA). The ETSU-R-97 guidance was based on an assumed component of AM in the form of 'blade swish', typically noticeable only in relatively near proximity to the source. The emergence of a form of AM that could be audible at long distance and with a lower frequency character ('thump'), together with the reported difficulties in applying Statutory Nuisance provisions to control AM on existing sites, has highlighted a need for a planning mechanism to control the potential impact of AM WTN from proposed wind farms. This research was commissioned by DECC to inform the development of a suitable control. This paper presented to Acoustics 2016 concentrates on the planning condition elements, whereas a co-authored paper presented to Internoise 2016 concentrates on the literature review elements.

2 PROJECT OVERVIEW

2.1 Aims

The objective of the research was to review the available scientific evidence concerning the human response to AM, evaluate the robustness of identified exposure-response relationships, and make a recommendation as to how a suitable control for AM might be implemented within the current UK planning system for wind farms. It was envisaged that, if sufficient supporting evidence was found, this could take the form of a rating penalty system, similar in concept to existing approaches to quantifying acoustic characteristics in wind turbine and environmental noise[12, 13]. The brief also included the aim to work closely with the UK Institute of Acoustics AM Working Group (IOA AMWG), which has independently researched and developed a method to detect and rate (in terms of physical magnitude) the AM in a wind turbine noise signal[14].

2.2 Project Team and Government Steering Group

The project was led by researchers at WSP | Parsons Brinckerhoff, supported by a group of external independent noise and health specialists. The work was directed by a Steering Group, comprising representatives of DECC, the Department for Environment, Food and Rural Affairs (DEFRA), the Department for Communities and Local Government (DCLG) and Public Health England (PHE), and the Devolved Authorities.

2.3 Structure

The project was undertaken in two Phases: in Phase One the approach was agreed and relevant stakeholders, information sources and search techniques identified. Phase Two comprised the research review and evaluation process, and the drafting of the findings and recommendations, including an external independent peer review and feedback period.

3 REVIEW OF EVIDENCE

3.1 Approach

A number of information sources were searched. Initially, the search results were examined by title and abstract, and papers with potential relevance listed. The sifting process highlighted a range of categories of study, which were separated according to classification.

The papers identified were categorised into either studies identifying the AM WTN human exposure-response relationship, i.e. both a quantified AM WTN component and a scaled human response, and supplementary studies (case studies, general wtn papers, etc.)

The abstracts of each remaining paper identified on the ‘longlist’ were examined. These papers were assigned a 0-9 rating of potential relevance against the study aims, which was used to prioritise the reviews of papers in each category. A total of 134 papers were identified, of which 69 were shortlisted for more detailed review. Of these, 15 papers were assigned to Category 1. One additional Category 1 study was identified after completion of the review stage (i.e. bringing the total papers identified for consideration to 135).

Reviews of each paper were carried out according to a bespoke structured review template to systemise the responses, prompting all reviewers to follow the same format and extract the same set of information from each paper (where available). The review template has been included as an appendix to the published report[15].

Potential publication bias in the search phase was minimised by accessing established reputable databases covering peer-reviewed (‘black’) literature in both science and health-related fields, and including ‘grey’ literature sources such as conference papers and industry publications.

The potential effects of selection bias (due to the application of relevance ratings and the categorisation process) are considered unlikely to be significant, mainly due to the relatively small number of studies into the AM WTN exposure-response relationship, i.e. Category 1. Category 2 material mainly provided supporting and contextual information and so any effect in terms of outcomes for the research is not be expected to be critical.

Risk of bias within the reviews was minimised by assigning each Category 1 paper to two external reviewers and resolving differences via discussion. The initial findings of the study were also subjected to an external independent peer-review phase, feedback from which was incorporated into the final draft.

3.2 Outcomes

A simplified schematic for possible factors important in AM WTN exposure-response is illustrated in Figure 1. The components making up this model are discussed below.

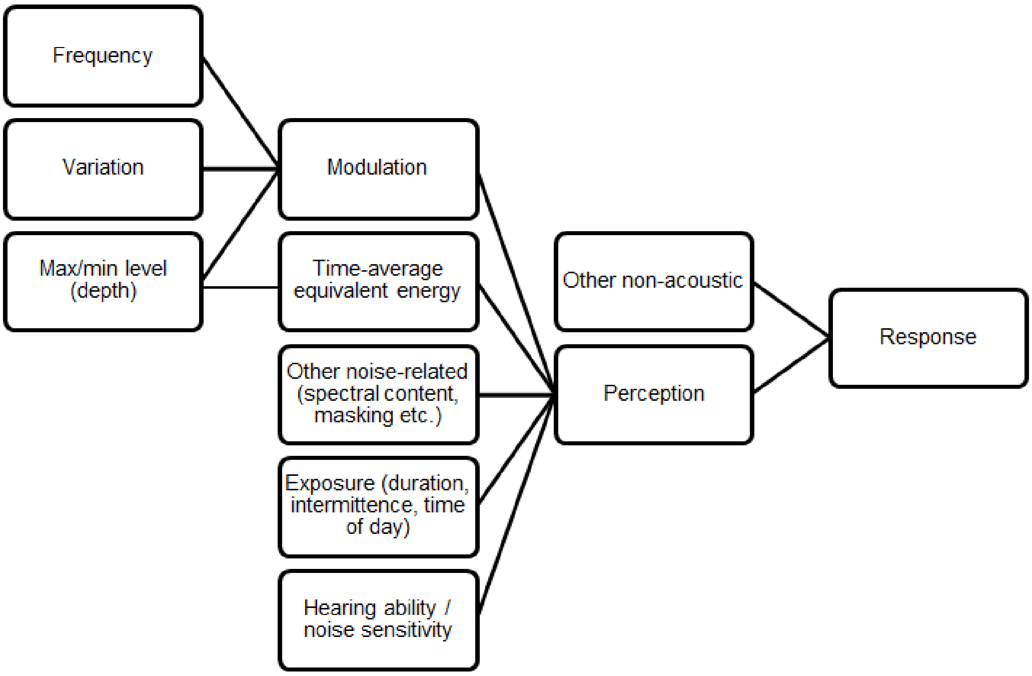

Figure 1 – Proposed schematic model for AM WTN exposure-response factors

3.3 Discussion

The evidence reviewed shows that, of the acoustic factors contributing to perception of AM in WTN, the time-averaged overall level and depth of modulation appear to be the most important and a combination of these parameters can therefore be used to express the expected response relative to a signal without AM. In terms of the average person, this equivalence seems to be in the region of 2-5 dB, and the perception of AM for most people increases from around 2 dB depth in the level envelope. Modulation frequency in the context of large-scale wind turbines has a small effect. The effects of duration, frequency and timing of AM occurrence have not been widely studied, though it seems clear that reports of adverse impacts are increased during the night-time. This could be due to increased prevalence of AM occurrence, or heightened noise sensitivity in domestic environments. It seems quite plausible that a combination of these factors could be expected.

The evidence reviewed supports the proposed use of a penalty regime for AM in WTN. In the absence of an ideal case-controlled AM exposure-response field study, the laboratory results offer the best available evidence to inform a penalty planning control.

4 PROPOSED PLANNING CONTROL

4.1 Planning Context

Current UK planning policy[16] requires any condition applied to pass 'six tests' for legal validity, which address the following requirements; a condition must be:

1. ***Necessary***: its entire scope must be required to make an otherwise unacceptable development acceptable;
2. ***Relevant to planning***: it must relate to specific objectives and the scope of permission;
3. ***Relevant to the development***: it must be justified by the specifics of the development alone;
4. ***Enforceable***: it must be possible to detect a breach, and for the applicant to remedy a breach;
5. ***Precise***: it must be clear what shall be done to establish compliance; and
6. ***Reasonable in all other respects***: it must not place unjustifiable or disproportionate burdens upon an applicant.

Policy also requires that 'significant adverse' impacts be avoided, while other adverse impacts should be mitigated and minimised.

The AM control has only been designed for use with new planning applications; applicability for use in Statutory Nuisance investigations on existing wind turbine sites, where the legal regime is different (and outside the research scope), has not been considered.

4.2 Key Elements

The recommended elements to form an AM penalty planning condition are shown in Figure 2. The prevalence of unacceptable AM was not evaluated as part of this study, but it is believed that the likely occurrence cannot be predicted at the planning stage with the current state of the art. It was concluded that the control would by necessity be instigated by complaints (i.e. a 'reactive' control).

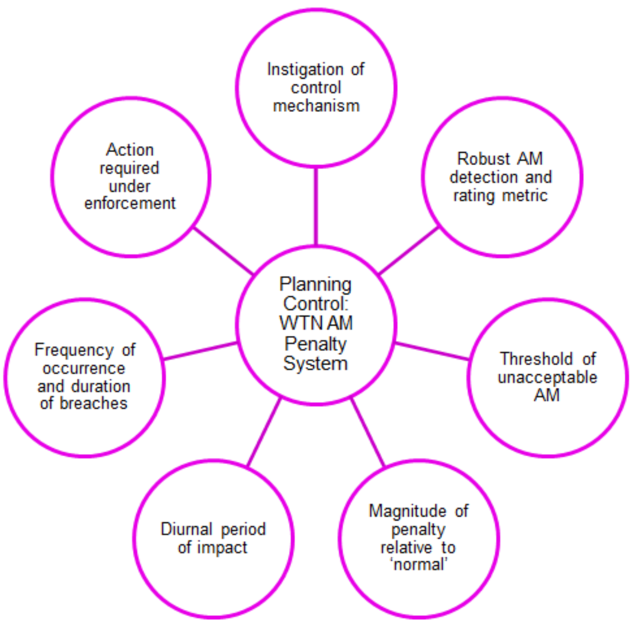

Figure 2 – Key elements to the planning condition

The IOA AMWG have conducted a review of existing approaches to rating AM, and developed a hybrid time and frequency-domain method that addresses shortcomings identified in alternative schemes. The output of this method is modulation depth (MD) derived from a reconstructed filtered time-series of the original A-weighted envelope signal; this is compatible with the exposure-response research evidence, and is believed to be a robust approach to rating AM[14].

The method is also based on 10-minute analysis periods, which makes it compatible with the existing ETSU-R-97 approach. Since AM is wind-speed dependant, the derived MDs would be separated by wind speed, enabling operators to identify the particular conditions leading to occurrences of high AM. It is noted that the IOA method is limited to a fundamental modulation (blade-pass) frequency of around 1.5 Hz, equivalent to 30 RPM for a 3-bladed turbine; this limitation means the proposed control addresses typical large-scale turbines but is not intended for smaller installations with higher rotation speeds.

The limitation to approx. 1.5Hz (due to the sampling rate of the method), does not affect larger turbines, but restricts the applicability of the method from smaller turbines, which, research suggests, may also be more annoying than their larger cousins. This should be taken into account if a smaller turbine is being considered, and an alternative approach may be needed.

The threshold and magnitude for an AM penalty have been derived from the evidence review, with the proviso that a 3 dB MD (just above the 2 dB threshold of perception) is considered normal within the existing ETSU-R-97 guidance; to avoid placing an unjustifiable burden on applicants (vis-à-vis the ‘six tests’) the proposed penalty starts at 3 dB MD. This is also supported by the evidence, which generally shows a relatively small difference in perception or response between 2 and 3 dB MD. The proposed regime is illustrated in Figure 3. The dB penalty is added arithmetically to the time-averaged level, similarly to the ETSU-R-97 approach to penalising tonality.

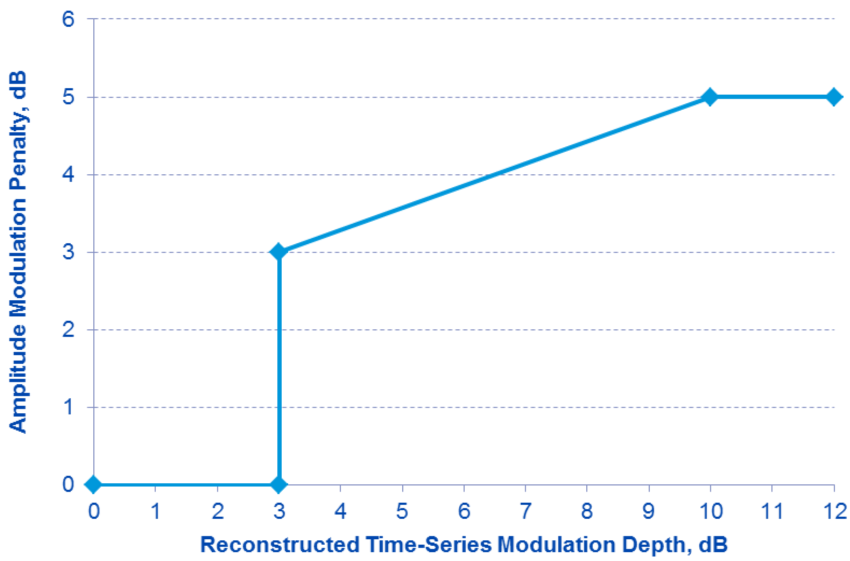

Figure 3 – Proposed AM level penalty regime

It is considered that since a wind turbine can exhibit both tonality and AM, the proposed AM penalty would be additive with that for tonality. This is consistent with the approach in BS4142:2014. However, both elements could be intermittent, and therefore should be analysed separately to establish the exact patterns for each element.

The review found that AM generates greatest adverse impacts during night-time or early morning periods. The ETSU-R-97 guidance includes a less stringent lower limit for the night-time (2300-0700hrs), which could have the result that a penalty added to the time-averaged level would result in a breach during the day, but not at night, when impact is expected to be increased. To address this discrepancy, it is proposed that for sites at which the night-time lower limit is less stringent, the difference between day and night limits would be added to the penalty, such that night-time periods would have sufficient protection. This also raises a wider question as to whether a less stringent night-time lower limit is congruent with a national policy of minimising adverse impacts.

In view of the lack of evidence available concerning the impact of occurrence frequency and duration of AM, it is proposed that this judgement is best addressed by the environmental protection officers investigating any complaints or alleged breaches; this approach is in line with the ways in which other forms of noise disturbance are currently handled in the UK. These judgements of impact would be informed by the number of 10-minute breaches detected, duration, time of day, sensitivity and so on. It is not envisaged that a single breach in any period would automatically trigger enforcement action; the expertise and experience of the officers will guide reasonable application.

The main purpose of the penalty is to bring about a reduction in the impact as a result of the period of unacceptable AM, and as currently proposed this consists of a two-tiered approach. The first tier would seek a reduction in the AM using engineering methods to reduce the AM to an acceptable degree of impact. Where the degree of AM cannot be reduced, the penalty should bring about a reduction in the overall level of WTN during periods of AM breach conditions (e.g. identified by wind speed and direction) such that overall limits are met, since this would also result in reduced impact from AM.

The previous schemes to deal with AM have been based upon an averaging process; however, although overcoming the issue of background noise[1], the averaging process penalises periods of non AM, and therefore was considered by the research team to fail the six tests. Whilst the end result may be a suitable control method for operators, it would not be reasonable for local authority officers to request that level of mitigation.

Further research is recommended to supplement the limitations of the available research which underpins the above proposal, although if the proposed control achieves the aim of reducing the impact from AM, then this research may not be required.

Given the gaps in current knowledge, the elements for the proposed control should be subject to a period of testing and review. The period should cover a number of sites where the control has been implemented, and would be typically in the order of 2-5 years from planning approval being granted.

5 CONCLUSIONS

WSP | Parsons Brinckerhoff has undertaken a review of research into the effects of and response to the acoustic character of wind turbine noise (WTN) known as Amplitude Modulation (AM). The objective was to evaluate the current evidence on the human response to AM, the factors that contribute to human response, and to make a recommendation to UK Government on how to decide what AM controls could be implemented through the planning system.

The work involved the collation and critical review of relevant papers, existing planning conditions, and existing planning policies where they relate to AM from wind turbines. The review established a need for AM control, a clear link between overall turbine noise level and

[1] Enforcement schemes will have to be designed to account for masking background noise

annoyance, and a correlation between the degree of AM and an equivalent level without perceived AM. Based on the evidence found, a recommendation was made on the elements required to construct a planning condition to control AM.

The review found that a planning condition should comprise the following:

1. It should be instigated by complaints about AM;
2. The IOA-developed rating metric should be used to quantify AM in 10-minute periods;
3. A level penalty should be imposed based on the modulation depth (MD) of detected AM; the threshold for which is 3 dB MD, and the penalty magnitude is a value between 3 and 5 dB over the range 3 to 10 dB MD;
4. The AM level penalty should be additional to any decibel penalty for tonality;
5. An additional decibel penalty is proposed during the night-time period to account for the current difference between the ETSU-R-97 night and day limits, to ensure the control method is effective during the night-time; and
6. Professional judgement should be used by statutory investigators to assess the impact of frequency and duration of any breaches identified, as for other types of noise source.

The elements for the proposed condition should be subject to a period of testing and review, covering a number of sites where the control has been implemented, in the order of 2-5 years from planning approval being granted. It is hoped that use of the control will lead to the development of more proactive approaches to prediction and mitigation of AM on the part of wind farm operators and developers.

The findings also suggest that the noise limits in ETSU-R-97, which in some instances allow a higher noise level at night, may not accord with more-recent Government policies aimed at minimising adverse impacts.

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