



Using Dynamic Noise Mapping for Pro-Active Environment Noise Management

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ABSTRACT

Since its first mention in 1999, Integrated Environment Noise Management has promised new possibilities for managing environment noise through the interaction between measurements and calculations. This has led to the technique of Dynamic Noise Mapping, where measurements are used to update calculated noise maps, which was primarily intended to improve local noise maps and supplement noise monitoring results. However, with the ever-increasing availability of internet communication and the rise of managed services which enable the efficient exploitation of new technology, integrating measurements and calculations for more pro-active environment noise management, where noise issues can be avoided, is becoming potentially interesting and possible. So, the link between calculation software and real-time noise monitoring solutions enables the automated creation of noise maps based on real-life noise and weather monitoring, giving feedback to enable a more optimal planning of operations within the noise limits. This dynamic mapping can be done with updates as regularly as every hour enabling industry to schedule operational activity, quickly assess the noise impact and ensure that they are doing the utmost whilst complying with noise limits. This paper describes how Dynamic Noise Mapping for Pro-Active Environment Noise Management works and its possibilities, challenges and limitations based on current knowledge and technology. The paper will also identify areas of future research.

Keywords: Environmental Noise, Measurement, Calculation, Noise Control

1. BACKGROUND

First mentioned in 1999 [1], Integrated Environment Noise Management has promised new possibilities for managing environment noise through the interaction between measurements and calculations. This has led to the technique of Dynamic Noise Mapping, where measurements are used to update calculated noise maps, which was primarily intended to improve local noise maps and supplement noise monitoring results [2].

Environmental Noise Management tools will support stakeholders, i.e. industry, neighbouring citizens and supervising authorities, in various ways. The point of view will, by its nature, vary between these stakeholders. The general interests of noise management may be summarized as follows:

Providing a realistic forecast of noise impact for the average and worst case situations

Optimizing the duration and intensity of industrial activities within noise limits

Documenting noise impact from monitored sources as well as of residual sound from other sources

In support of these targets, a combination of measurements and calculations can be used to fulfil tasks such as to:

- Improve a source emission model (level, spectra, directivity)
- Separate source description of sources out of reach
- Recognize potential weaknesses in machinery
- Determine residual noise levels

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- Determine propagation parameters (meteorology, ground effects, screening)
- Determine adequate positions for measurements
- Optimize industrial activities with respect to duration and position
- Ensure optimal “land use” where new industrial compounds are planned next to settlements

Globally, different regulations are used. For simplicity, the examples in this paper use ISO 9613[11]. In addition to the basic principles of ISO 9613, other aspects relevant to this topic are:

- Use of octave band or average frequency
- Use of meteorological corrections
- Use of uncertainty strategies

2. COMBINING MEASUREMENTS AND CALCULATIONS

The principles of Dynamic Noise Mapping using the technique of reverse engineering are described in [3], [4], [5] and in [6] where a collection of good practice was also collated. Real-time noise measurements are collected and used to apply corrections to emission models. The basic steps of Dynamic Mapping are:

1. Assume nominal emission values for the unknown or variable sources
2. Calculate the noise level at the receiver (i.e. measurement) positions
3. Add the difference in the measured and calculated sound pressure levels to the source emission power level
4. Perform noise contour calculations based on the new source emission

More than one source and measurement position can be performed in parallel, increasing the degrees of freedom of the system and typically leading to an increasing range of acceptable solutions, depending on the placement and number of measurement positions. Thus, with multiple source-receiver combinations, the reverse engineering process is iterative, continuing until a pre-set error limit is achieved or until a set number of iterations (e.g. 10) have been run. It is possible to set limits on the variation of an individual source so that its emission is realistic. It is also possible to link sources together either with equivalent or with relative emissions. This grouping of sources reduces the degrees of freedom of the system to be resolved.

Note that it is important to correctly compare the measurement and calculation values to ensure that they represent the same parameters - this may require corrections to the desired parameter due to individual microphone positions may be desirable [7][8][9].

While using any noise calculation software, the user will have to provide input to describe the source model as well as the propagation model. Site knowledge, personal experiences or database information will typically be available to create rough estimates. To improve quality the user will refer to site-related measurements. Any distinct and representative source emission measurement will improve the source model, thus providing a more realistic forecast. Whenever more than one measurement is taken at the same time and with focus on the same source situation, the redundant data can be used to investigate further details of the model. “Reverse Engineering” can be used to analyse measurement data in various ways and to improve model data, such as:

- a) Average source levels including source separation
- b) Source levels in a spectrum including source separation
- c) Source directivity
- d) 3rd party background source levels
- e) Ground surface condition
- f) Meteorological condition
- g) Screening

A more detailed model will again help to produce a more realistic noise impact analysis and improve the chances of qualified forecasts of noise impact from planned industrial activities.

Noise maps will be available which reflect the situation in the whole area and not just at a few measurement positions. Based on such maps, purpose-related measurement locations may be determined, e.g. to find the worst impact place or best places to identify specific or residual sources.

LimA’s “Reverse Engineering” method [10] was originally designed to determine source levels in situations where one cannot access the source near enough to be able to neglect the effects of

background noise or propagation influences, such as screening or reflection. If more than one unknown source influences measurements, a number, N , of simultaneous measurements (or measurements under the same conditions) are needed to determine the emission from the same number, N , unknown sources. It is advisable to use more measurements than there are unknown sources in order to over-determine the model. ISO 9613's theoretical model [11] is an estimation of reality. In addition, the model which will be set up as basis for any reverse engineering process is only an estimation of the real geometry as well as the real source levels of any sources not subject to the iteration process. Therefore, some discrepancy (uncertainty) in calculated levels compared to the measured noise levels can be expected.

In the process of "Reverse Engineering" this deviation is minimized through an automated, iterative, process, typically on basis on energetic levels. The automation will allow handling a large number of sources even with separate spectra, e.g. representing a whole industrial compound as it was shown by Vukadin et al. in [12].

Concerning the above listed analyses:

Case a) can be handled by the basic approach of Reverse Engineering as described above.

Case b) will already need an extra step after finding best fits for each octave or 1/3 octave, the total error for the overall noise levels needs to be optimized on top.

Case c) can be reduced to a situation with an increased number of sources that only propagate into a certain direction. At the measurement location, the measurement may contain components of directivity related to the direct sound from the source as well as due to reflection and thus including the emission due to a different angle of directivity.

Case d) will automatically be counted for when potential background sources are introduced into a model, even with a low initial noise level. Wherever emission levels for the constellation of sources within the industrial site cannot be determined from the measurements without a large contradiction between calculated and measured levels, a residual noise level must be introduced which will automatically reduce the error

Case e) will involve a more "manual" process. In order to avoid human error, the authors recommend that this process be integrated into a semi-automated workflow such as supported by LimA and described below. For the example of determining the "unknown ground impedance, G " a model might consist of several regions which are classified in, for example, 3 groups. For each group, G may be defined in steps of 0.2 between 0.0 and 1.0. The workflow finds the combination of G values which produces the best match between calculations and measurements. Information is kept in a "history" database for re-use in the future for similar circumstances.

Case f) might be treated similar to case e). In most current practice, the focus is on the use of noise measurements alone. However, weather also affects noise propagation. Thus, one can consider weather as a variable to be determined through a combination of noise and weather monitoring. At the moment basic formulae as they are used by German authorities are applied in order to estimate C_0 values for a long term average based on known wind statistics. Though it has not been dealt with in this manner up to now, these formulae might be modified for local relations and take into account not only wind direction but wind speed as well.

Case g) should perhaps be seen as a method of quality assessment. Even in the case of a single relevant source, more than one measurement might be useful. The redundancy can be used to indirectly check the model. In practice, this means that a bad match of calculated and measured data will indicate weaknesses in the model enabling further investigation of the site and model in more detail.

3. WORKFLOW SUPPORT IN NOISE CALCULATIONS

Workflows are scripts which are designed using LimA's macro language. A workflow will make use of several LimA modules and potentially any 3rd party software as well. This is best illustrated with an example taken from one of the above cases.

The analysis for case e) demands setting up and calculating 216 different model situations, i.e. combinations of G values for the ground model. The principle steps of such a LimA workflow are:

Read meteorological condition from external file which describes the measurement situation, e.g. XLS (csv) file with temperature, humidity and distribution of wind direction

- Calculate C_0 values for different directions as required by ISO 9613
- Feed C_0 values, temperature and humidity into calculation parameters

- Read up to date measurement data from the 3rd party software or database
- Update MEP objects (measurement positions), i.e. update the measured noise levels as well as the new measurement position in the model
- Initialize model data by setting all attributes G (impedance) to 0.0 for all TOP objects (topography)
- and initialise “smallest overall error” to large value.
- Start DO LOOP for all 3 ground region types
- Start DO LOOP for G value varying from 0.0 to 1.0 in steps of 0.2
- Start Reverse Engineering calculation
- Read overall calculation error from from the calculationLOG File
- Test overall error against “smallest overall error” and store combination of G values as well as error if values improved.
- Redo for all G from 7.1.1 on
- Redo for all regions from 7.1 on
- Create final map for best fitting G values and store G values and meteorology in “History” data base

4. ADDITIONAL PLANNING TOOLS IN CALCULATION SOFTWARE

The methods described so far do enable the use of “a state of the art” noise model and prediction software in support of typical noise management tasks at best quality level. In addition, these may offer:

- **Manual decision making:**
Considering an open cast mining area with a couple of settlements in the neighbourhood, this may for instance involve decision making with respect to individual equipment. This is where source management comes in and the user is offered a menu to manipulate source data, e.g. simulating the used of improved conveyer belts. While applying a change, he will instantly see the effect on any of the relevant receiver positions in the neighbourhood
- **Influence maps:**
In another scenario, the influence of large excavators working along a given track needs to be documented – either as an extra graph per source-receiver combination or as an overall plan view picture, where the influence of each excavator is documented for different positions along the track – for example, concentrating on the 5 most important receiver positions per track
- **Fixing Quotas:**
While working with machinery of considerable noise emission, it may be necessary to comply to a limited L_{eq} value at different locations. Depending on how the allocation of machines to different potential work places is organized, the limit will be reached after differing durations. This task can be described by optimizing emission levels in a similar manner as this is done while “Fixing Quotas” for planned industrial compounds. Fixing Quotas uses a similar approach to “Reverse Engineering”. “Reverse Engineering” matches measured receiver values best, allowing undercutting and exceeding for calculated receiver values. “Fixing Quotas” has pre-defined upper limit receiver values, which may not be exceeded by calculated values.
The automated optimization in the process of Fixing Quotas defines the L_w for each unknown source in the model so that the highest total emission is created that does not exceed any limit values at the receiver positions. This determines the maximum amount of time that machines may operate and the best places for positioning the equipment.
- **Recognizing non critical areas:**
As open cast mining areas are typically widespread regions, there might be large areas where the use of any noise equipment will has negligible influence on the surrounding protection zones.
A workflow may be created to easily visualize such regions for planning purpose. Here the user only selects the height of the source, the height of the relevant receiver and the potential emission level of the source. Critical receiver positions are placed bordering the settlements. The workflow automatically manipulates the model, placing a source at the

receiver height every X m along each borderline. Those parts of the model outside the area of interest are erased to reduce calculation load and a grid for the whole region is calculated with receiver height being set to the source height. As this actually inverts the model, the meteorology effects need to be inverted as well by rotating the North orientation by 180 degrees. During grid calculation, LimA automatically only takes into account the most relevant source and a map is created.

- **Influence Maps and Grouped Sources:**

In LimA each source object may be assigned an index NEG (Noise Emitter Group index). Processes mining may be better represented by several sources than by a single one. Assigning one NEG value to all sources related to a process helps evaluate its environmental impact. By keeping track of the most relevant NEG, LimA enables influence maps to be created showing the area where a specific process has the highest impact. Influence maps can also be used to find most representative measurement positions to monitor such a process. The map might also be helpful when looking for areas where background noise will be measured best.

- **Uncertainty:**

Uncertainty will affect the prediction results and will as well influence our determination of any source levels when doing so with help of reverse engineering. To estimate effects of uncertainty, one can produce two sets of result, one based on the standard situation and another based on the situation with the model modified according to defined rules to increase noise levels. Both results are compared with the help of in-built statistic tools. Maps will show the noise level differences (rise) due to uncertainty. The increase will be small in areas where many sources contribute equally to the total receiver value. Those areas with small uncertainty should be chosen as measurement locations to get the best representativity.

Three aspects of uncertainty are worth noting here:

1. Distance related uncertainty is described in ISO 9613. In addition, the environmental authorities of the State of Brandenburg, Germany (LUA Brandenburg) made a proposal, suggesting a weight correcting in relation to the distance within a distance range of 100m – 5000m. E.g. $D_{UcDis} = A * \log(d_s)$ for $A=1$ will produce an increase due to uncertainty of 2 dB for 100 m and a correction of 3 dB for 1000 m. This is within the range described in ISO9613, i.e. 1-3 (db) for up to 100 m and 3 dB for up to 1000 m. The suggestion formula will however avoid jumps in values and might be calibrated for different weather conditions by varying factor A.

As a result of a longer monitoring period, within which those parameters such as wind, temperature and humidity which influence propagation according to ISO 9613 are in circa similar for a number of occasions, the system might built up its own “experience database”. From this, a general correction for propagation uncertainty may be extracted for different meteorological condition

2. Source related uncertainty is dealt with by input of a standard deviation per source. Also here sources can be grouped and this will influence the receiver levels, as the group will be treated as a coherent emitter.

3. Setting up a model which represents the exact source and receiver positions in an exact terrain model may be difficult, particularly with limited economic and in an area which is constantly being reshaped. In LimA the user may define a potential inaccuracy of obstacle positions in relation to source positions. During calculation this data will be used to reduce the screening effect of any edge. By comparing results, one may determine where measurement positions or relevant source positions are unambiguous.

5. PRO-ACTIVE ENVIRONMENT NOISE MANAGEMENT

In our environmentally conscious age, industries are facing tighter restrictions than ever before. As settlements near industrial sites grow along with their inhabitants’ expectations, environmental noise has to meet demanding limits and often leave little room for new development. Brüel & Kjær’s Environment Management Solutions business unit has spent the last 20 years working with airports on smart environmental noise monitoring, and developing technological solutions that manage noise annoyance. It’s through these extensive relationships that Brüel & Kjær has come to embrace the

concept of building ‘environmental capacity’ as the best way of encompassing and explaining a multi-faceted approach to durable noise management.

According to the Joint Group of Experts on Scientific Aspects of Marine Environmental Protection, environmental capacity is defined as “a property of the environment and its ability to accommodate a particular activity or rate of an activity ... without unacceptable impact.” Broadly, what this means in terms of noise management is the willingness of the local community to accept given noise levels at different times, but in fact it is far more nuanced than that.

Environmental capacity is not externally enforced like a law or a limit, but it is the self-evident collection of variables that define the limits for change – the mandate that comes from the local community. So rather than looking at noise management responsibilities as merely staying under a limit and reacting to complaints, thinking in terms of environmental capacity encourages businesses to focus on what they can do within the tolerance limit of the community. Importantly this includes building spare environmental capacity that enables business growth by facilitating change.

From the perspective of the operator of an industrial site, the key thing is that environmental capacity is not fixed, and it can be improved and bolstered. Accordingly it’s all about improving perceptions through transparency and public engagement, so that communities are more willing to accept change. Within the aviation industry, a twin-armed approach has proven to be the most effective, with impact reduction on one side of the equation, and tolerance building on the other.

One of the key areas is the ability to anticipate and prevent unnecessary noise rather than just report levels and reacting to noise complaints, something that is now possible in commercial solutions such as Brüel & Kjær’s Noise Sentinel [14]. This management of noise in real-time enables the operator to manage operations within noise restrictions, alerting operation staff of actual or even potential noise threshold exceedances. This allows immediate, timely reaction to the noise situation, ensuring compliance with limits and reducing the disturbance to the neighbouring community, thus also increasing tolerance as well as reducing impact.

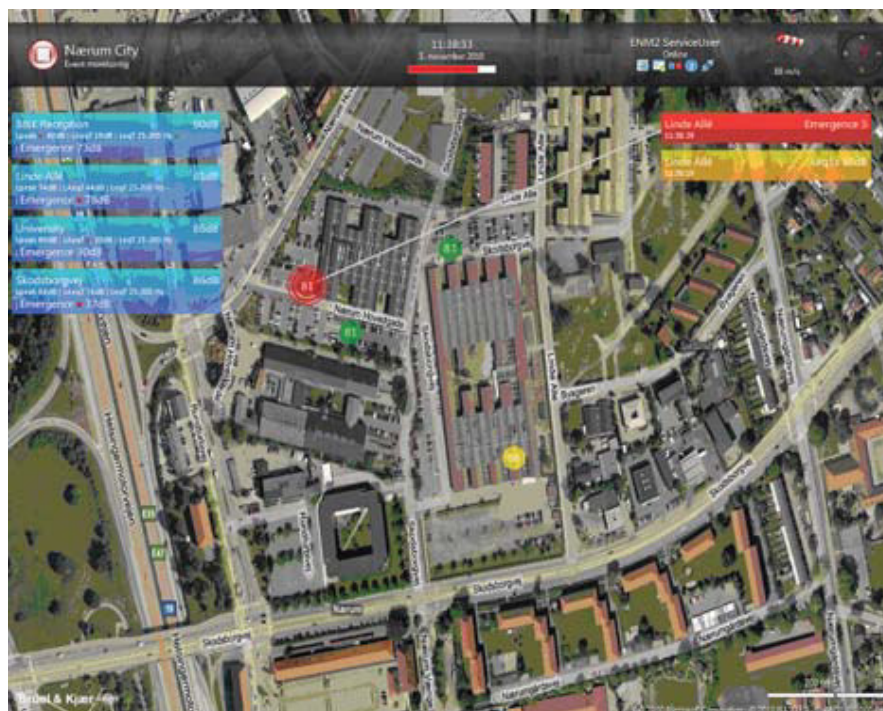


Figure 1 – Noise Sentinel's Real-time Noise Control application showing warning and exceedance alerts

During operation, the operators can see a map of the surrounding area with the monitoring locations identified and showing the current noise levels, colour coded depending on the noise limits. Alerts may be triggered based on simple overall or frequency-limited noise levels exceeded over a particular duration, or even as a more complex compound parameter based on any of the real-time inputs. These alerts appear on the screen to indicate that noise levels have exceeded the defined criteria. In addition, warnings are shown indicating that the criteria will be breached if noise

continues at the current levels.

Alerts remain displayed until action is taken by the operator. Selecting an alert will show additional information including where it occurred and enable the user to replay the sound that caused the alert, aiding identification to confirm if it is their responsibility. After investigating the alert, the operator may enter details including the cause and any other factors that should be recorded. Once applied, the information is recorded along with the exceedance information and reported back to the employee in charge of environmental noise issues on a regular basis.

With more detailed analysis, equipment improvements and noise barriers can be readily assessed. Quicker feedback calculations on new operating practices allow operators to build detailed 3D maps of their noise output that reflect their current activities around the industrial site. The result is continually assured compliance with noise levels in real-time that allows the operator to adapt their practices and to work right up to the limit where practical.

6. DYNAMIC MAPPING IN PRO-ACTIVE ENVIRONMENT NOISE MANAGEMENT

Industrial sites want to have real time feedback to make operational decisions. The more locations that can be assessed, the better. However, it is expensive to deploy, operate and maintain monitoring systems for this purpose and thus interest has grown into whether dynamic noise mapping can be a viable alternative.

Owners want to model the industrial site operations in a particular area under expected weather conditions and use the model to check whether they will exceed perimeter noise limits. If the model says that results are acceptable, they will go ahead, if it says they will exceed then they will change operations either in location or in type and amount of work. They then monitor the actual operations to check that they stay under the limits.

The authors have, in recent workshops, identified that the dynamic noise mapping technique for setting operation conditions for real-time noise management is suitable for a range of industrial operations. Weather is a key issue. Real-time weather monitoring is available. The user must be able to accurately determine the occurrence of temperature inversions. This is probably possible by setting up simple rules for entry into the calculation software. Wind data (speed and direction averages) is also required – this is widely available and can easily be integrated.

Dynamic noise mapping operates for the assessment of energy-average levels over periods of 1 hour or more. The majority of noise legislation requires compliance with periodic (Day, Evening & Night) limits built up around energy-average (Leq) levels. Here, dynamic noise mapping is suitable for setting operation conditions for real-time noise management. Some legislation requires statistical and maximum levels. For statistical levels, provided that safety factors for incorrect assessment are used, dynamic noise mapping is suitable for setting operation conditions for real-time noise management. For maximum levels, there are no proven algorithms that can accurately predict these values. Thus, the authors do not recommend using dynamic noise mapping for setting operation conditions for real-time noise management where compliance with maximum levels are required.

Moving sources can also be modelled and, in principle, used in reverse engineering and dynamic mapping. However, research is needed to make this operational.

It must be noted that the more complex the topography, the less accurate the algorithms become. On the positive side, recent developments in the latest algorithms promise far superior modelling in complex terrain. However, in practice, the calculation loads will increase and will affect the maximum update rate even for larger systems.

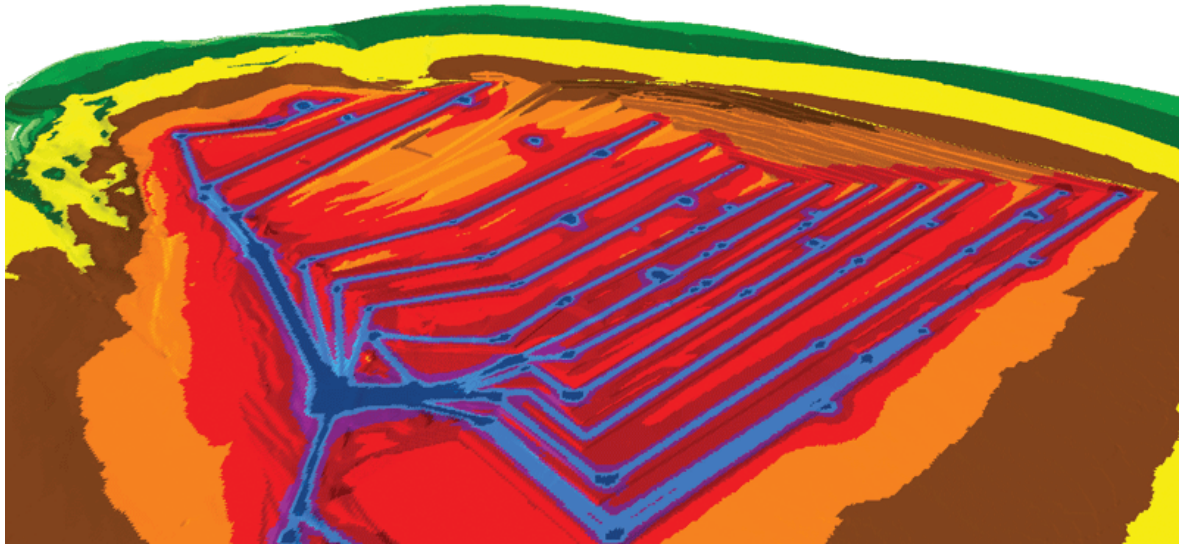


Figure 1 – Results of dynamic noise mapping for a mine

7. FUTURE RESEARCH

The technique assumes that the legislation does not require the addition of penalties for impulsivity and tonality. If these are required, then estimates may be made. However, the assessments, particularly for tones, would be conservative and thus may not optimally utilize the actual available environmental capacity.

Future development could cover the development of algorithms to better estimate statistical levels and to implement relevant algorithms for the estimation of blast noise in accordance with related international standards. Once implemented, feasibility studies could be performed to determine the applicability of these algorithms to the estimation of maximum levels.

Using a set of predefined sources, each with their own footprint would be a sensible development. If the sources are stable and variable levels are measured, it will be due to short term weather variation. If a set of pre-calculated meteorological conditions (wind and temperature inversions), then the system can give a suitable response time.

The limiting factors in the current dynamic noise mapping technique for use in real-time noise management are:

- No impulsive noise algorithm implemented (maxima and blast noise)
- No algorithm implemented for determining statistical values
- No algorithm or documentation of the effects of short-term variation in wind speed and direction (wind speed variance is the most time-varying factor). This limits the assessment period to several minutes. Currently dynamic noise mapping is linked to the resolution of the measurements (currently 1 hour) and the calculation power in the system relative to the complexity of the model. A feasibility study is recommended to test the applicability at resolutions of under 1 hour. My first estimate is that a minimum duration of at least 5 minutes could be achievable with the current scientific knowledge
- How does one measure/predict temperature inversions which have a great impact on propagation? One theory that needs to be tested is that, as temperature inversion will give the same propagation in all directions while wind effects are directional, then this can be used to determine the temperature inversion factor, provided that the source emission is known. Thus, with known sources and the identified weather conditions, the situation can be calculated and the source levels monitored to adjust the actual operation required to comply with legislation. For this, calculation capacity is available only for simple models with one or two sources. For large areas, the calculations will be very intense and will be too slow for practical use.

- Current nationally accepted algorithms (eg ISO 9613) do not include the effects of specific weather conditions. However, newer methods, implemented in our software (Harmonoise) do

The above are potential candidates as areas of future research.

8. CONCLUSIONS

Dynamic Noise Mapping was primarily intended to improve local noise maps and supplement noise-monitoring results. With the ever-increasing availability of internet communication and the rise of managed services that enable the efficient exploitation of new technology, it is now ready for use in more pro-active environment noise management, where noise issues can be avoided. The link between calculation software and real-time noise monitoring solutions enables the automated creation of noise maps based on real-life noise and weather monitoring, giving feedback to enable a more optimal planning of operations within the noise limits. This dynamic mapping can be done with updates as regularly as every hour enabling industry to schedule operational activity, quickly assess the noise impact and ensure that they are doing the utmost whilst complying with noise limits. This paper described how Dynamic Noise Mapping for Pro-Active Environment Noise Management works and its possibilities, challenges and limitations based on current knowledge and technology. The paper also identified areas of future research.

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