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Developments in specific noise determination in continuous unattended monitoring systems

Douglas MANVELL[1]
Brüel & Kjær Sound & Vibration Measurements A/S, Denmark.
Ken ANDERSEN[2]
EMS Brüel & Kjær, Denmark.

Summary

Continuous, unattended noise monitoring systems can immediately alert you should noise levels exceed defined criteria. Once alerted to an exceedance, operators can act to return levels to compliance. This approach has two significant limitations. Firstly, the operator can only take action after the breach has occurred and therefore systems are only able to inform owners about problems that have occurred in the past, rather than allowing them to maintain compliance. Secondly, the noise limit exceedances might not be due to specific noise from the operator but from unrelated, residual noise in the often-complex noise climates around the particular site and will then be the cause for a false positive. Compliance breaches are frequently triggered by aircraft overflights, road traffic or community sources. Modern monitoring systems enable users to view noise characteristics and listen to the noise breach to determine the source and act if necessary. However, this approach can create a significant number of false positives each taking up operator time to address. A previous paper by the authors described how airport noise management systems have addressed this problem by combining data from other systems, and how different techniques are required in urban & industrial noise management. This paper describes developments in these techniques and gives examples of techniques that allow operators to take action before a compliance breach occurs, and to reduce the number of false positive alerts.

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1. Introduction – the need for specific noise determination

Noise legislation is typically based on the assessment of noise from a specific source against legal limits [1]. Noise limit exceedances might not be due to specific noise from the operator but also from unrelated, residual noise in the often-complex noise climates around the particular site, as conceptually indicated in Figure 1. Compliance breaches are frequently triggered by aircraft overflights, road traffic or community sources. It is difficult to separate specific sounds from the residual sound [1] with manned measurements. When continuous, unattended noise monitoring is mandated, this becomes an even bigger challenge as there is no operator present on-site to note causes. However, using additional technology and automation offers additional opportunities not always available with manned measurements.

Unattended systems need to pick out noise sources that are relevant. Thus, intelligence is added to better identify sources and reject irrelevant noise.

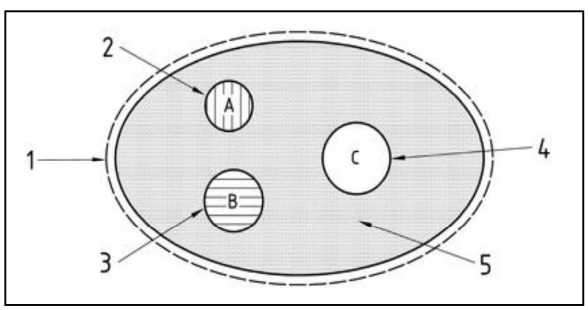

Figure 1. Three specific sounds A, B and C under consideration (2, 3, 4), the residual sound (5) and the total sound (1). Source: ISO 1996-1:2016 [1].

[1] Douglas.Manvell@bksv.com
[2] Ken.Andersen@bksv.com

This paper partly builds on a previous paper [2] by the authors on how airport noise management systems have addressed this problem by combining data from other systems, and how different techniques are required in urban and industrial noise management.

2. Early developments in continuous unattended noise monitoring systems

Airports have long been the driving force behind continuous unattended noise monitoring for several decades. So much so that standards have been developed. ISO 20906:2009 [3] is the latest international standard in this area. Airport noise monitoring has developed on event detection-based systems as the specific noise is short-duration and thus quite-well suited to this approach, when data transfer from monitoring terminals was difficult and expensive, resulting in the need for data reduction.
The initial approach was to use noise events which look at the broadband noise envelope. This works because noise from commercial aircraft has a certain duration, around 10-20 seconds, which distinguishes it from road traffic, for example, which is much shorter.
A noise event is detected when, for example, the sound level exceeds a threshold level by at least a specified amount for a specified range of duration and, importantly, when an event terminates, the sound level does not rise again above a specified level within a specified time, as illustrated in Figure 2. In most cases, the measurement of the sound pressure is integrated over the duration of the aircraft event. To enhance reproducibility, the event level requires the integration of the sound pressure in at least the range above the level '10 dB less than $L_{p,AS,max}$'. However, this requires that the event is significantly above the residual sound. For an acoustically reliable measurement, the aircraft event should be clearly distinguishable from residual sound, i.e. the difference between the level of the background sound and the sound level at the onset of a measurement should be at least 5 dB [3]. This places restrictions on the location of noise monitors to sites where the maximum sound pressure levels, $L_{p,AS,max}$, of aircraft events are at least 15 dB greater than the level of the average

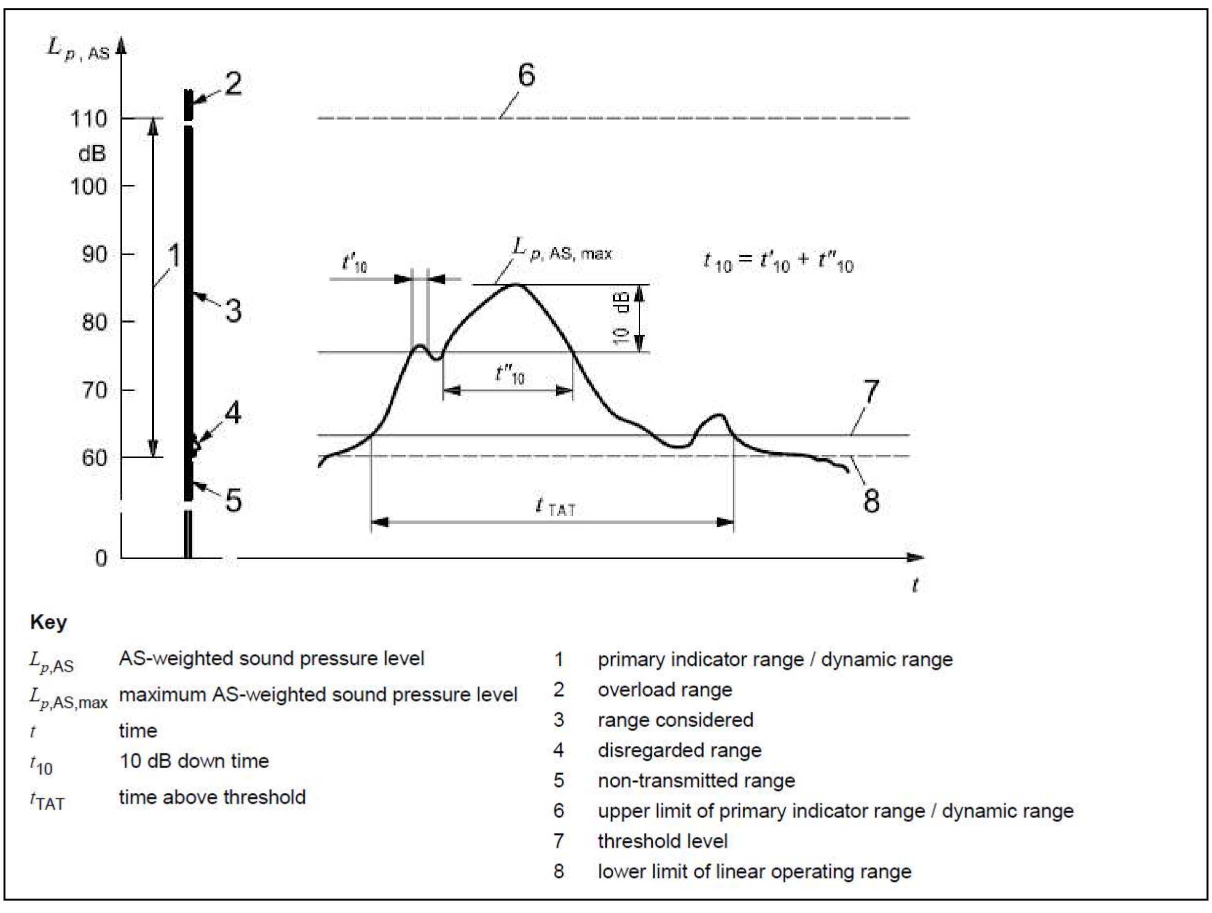

Figure 2. Noise event detection. Source. ISO 20906:2009 [3].

residual sound. This technique is implemented in a wide range of commercial solutions such as Brüel & Kjær Noise Monitoring Terminal Type 3639 [4]. Enhancements on the above include using floating threshold levels for the event triggers rather than absolute levels. These floating thresholds can be periodic or determined by the actual residual sound levels as determined by the monitor. An example of this is a L_{Aeq} threshold which is set hourly at 45dB above the L_{90} of the previous hour.

3. Further techniques developed in airport environment management

Modern airport monitoring systems enable users to view noise characteristics and listen to the noise breach to determine the source and take action if it is relevant. However, this approach can create a significant number of false positives each taking up operator time to address and are generally not sufficient to efficiently resolve the problem. Therefore, airport noise management systems have addressed this problem by combining data from other systems. The greatest single enhancement in the noise event technique is to link noise events to actual aircraft movements. This enables systems to link a specific noise measurement, to a specific aircraft [5], [6], as illustrated in Figure 3.

Although simple in principle, the algorithms required to accurately identify aircraft noise and their sources with high reliability and low error are relatively complex as they involve time-based correlation to flights plans and/or distance-based correlation to radar and have to ensure that all flight operations are included. More advanced techniques have been developed on the basis of noise events. Work has been done to look at the rise and fall times

Figure 3. Online noise exposure correlated to flight track information enhancing airport community relations [5].

of flight-induced noise events to further reduce data for analysis.

State-of-the-art airport noise management systems go even further, by applying data from noise models and past measurements to learn, for example, that an A380 has a certain noise level at a certain location for a particular type of operation. If the measurement isn't right, then it is flagged for manual review. This improves the reliability of source allocation and in turn the noise energy associated with aircraft operating at the airport.

4. Application to urban and industrial noise management

Urban and industrial monitoring is different. For industrial sources such as those in construction sites, petrochemical plants, waste recycling plants, mines and ports, there are a wide variety of sources of specific sound and residual background noise and, thus, we must separate them based on other characteristics. Traditionally, noise events, developed for use around airports with necessary data reduction at the noise monitoring terminal, have been used. Noise events are successful in many circumstances but are not always suitable for industrial applications as the sources have more variable noise signatures and are often not discrete. In some cases, particularly large mines, monitoring takes place at the community boundary up to 10 km away from the noise sources – where community noise is often much louder than the specific noise of interest. Moreover, monitoring at a mine site, includes a wider range of sources with different characteristics and it is not possible to easily separate them from background noise like an aircraft. Mine noise from rock crushers, for example, generally starts and continues for hours. Here statistical parameters and long-term averaging often are useful, thus avoiding influence from transient events caused by the community. Applying the L_{10} value over a time-window of multiple hours successfully distinguishes it from much shorter duration but higher-level community noise.

Although some techniques used in airport noise management systems can be and are used, or are adapted to the situation, different techniques are required in urban and industrial noise management in order to separate the specific sounds under consideration. In addition, techniques that allow operators to take action before a compliance breach occurs have been developed.

4.1. Modern techniques for industrial noise monitoring

Modern monitoring systems enable users to view noise characteristics and listen to the noise breach to determine the source and take action if it is relevant [8]. However, without further intelligent techniques this approach can create a significant number of false positives each taking up operator time to address.

While airports use radar and flight paths to correlate with noise events and reduce the workload of identifying the sources of these events, industrial applications do not have this input. What many of them do have, however, are electronic Operational Logs and SCADA (Supervisory Control And Data Acquisition) [7] systems which provide control and status of remote equipment for display or for recording functions. This provides similar correlation functionality as for airports, and more powerful if a real-time data interface can be established. Advantageously, data may include detailed information of the relevant operating condition.

Also, technical developments within modern monitors are increasing the efficiency of specific noise determination. As an example, directional noise monitors comprising three outdoor microphones positioned a precise distance apart in an array, can be applied in an industrial setup [9]. Here, digital signal processes analyse the three signals in real-time to deduce the level and directional component to accurately determine where noise is coming from. This enables users to determine if it is due to an industry or process or if it can be attributed to another source. This effectively improves the signal-noise ratio of the noise monitoring terminal by several dB, helping to reduce the number of instances where noise limit breaches require investigation and documentation.

Moreover, a range of practical solutions such as placing noise monitors closer to the sources and extrapolating results to the reference locations (boundary or noise sensitive locations) can prove beneficial provided that the difference in levels can be determined and successfully explained to the authorities and surrounding communities.

Other, more advanced techniques have also been used but with limited success, often due to cost considerations or due to the method's reliability with the range of sources and sound signatures involved. So, with the current state-of-the-art, in order to provide efficient noise monitoring, it is back to the drawing board.

4.2. Developing from noise events to the Alert technique

A noise monitoring and management system must be designed to include all exceedances that can be attributed to specific sound while minimizing those caused by residual sound. This helps to optimize the costs of designing and operating the system. The objective is to reduce investigations of breaches to a manageable level. What must be avoided is a situation where breaches are missing as this makes documentation and communication with authorities and communities unreliable and unmanageable. The aim is to provide intelligence to better identify sources and to reduce the workload of rejecting levels from irrelevant sources of residual sound.

One recently-developed technique which is becoming more widely used is Alerts. This is a 2nd generation noise event technique that provides greater flexibility and more effective use of available information. Instead of detecting events from isolated data within each individual monitor and communicating the information directly to the system users prior to any correlation of data and further analysis, the Alert technique opens for a more holistic approach. An approach where it is possible to process and correlate all input data from the sensor network in any conceivable combination to identify more intelligent and coherent Alerts, see Figure 4.

The Alert technique often utilizes a real-time connection from the different type of monitors to a server for better utilisation of the server's processing power to collect, process and analyse data from separate measurement channels across various locations and types of measures. In the event of lost connection, a professional implementation of this technique requires that

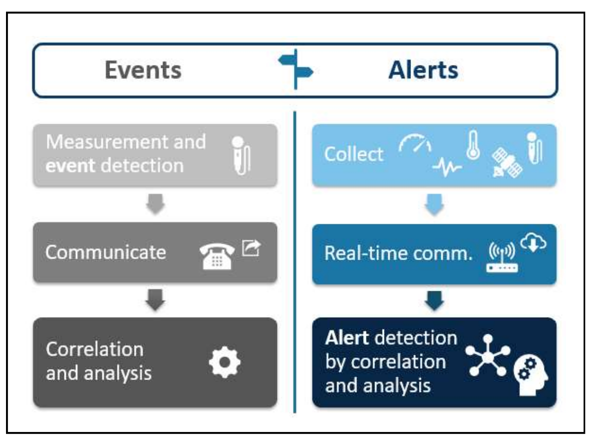

Figure 4. Illustrative comparison of techniques based on noise events and on Alerts.

Alerts are calculated on all data, both live and historical, to ensure full temporal coverage of the compliance limit monitoring, thus giving authorities and communities confidence in the site owner's reports.
Being done server side enables data measured by the environment management system (noise, vibration, weather information, air quality etc.) to be combined with SCADA systems, e.g. using web-services, to provide insight into operational activities and, importantly, enable automated operational management to optimize utilization of the environmental capacity, thus optimizing output form the site while remaining within the legal requirements.
Typically, the Alerts are defined as either Warnings (imminent danger of exceedance) and Alerts (actual exceedances). Often the Warnings are 3-5 dB below the Alerts.

4.3. Characterisation of Alert Rules

The characterisation of Alert rules is most often directly related to the compliance parameters and limits in the relevant legislation and standards applied to the site. Thus, if the compliance limits are the specific L_{90} levels over synchronous 20-minute periods, then the Alerts are set up to determine these levels. However, if, for example, noise compliance is in danger of exceedance only when the wind is blowing in a certain direction, then only those cases where the weather monitoring also fulfils these conditions are included. Moreover, including a weather station to your monitoring system will bring the opportunity to deactivate noise alarms when wind speeds are above a certain level again with the similar intention to exclude residual noise and avoid generating false positives. Information about wind speed could also be used for correcting a measured sound pressure by subtracting the wind influence. More parameters related to the weather condition such as temperature, atmospheric pressure, humidity and liquid-equivalent precipitation, can be followed closely by a weather station.
Another strong tool for excluding residual noise, is by combining Alerts with directional noise monitoring which can, in addition, help to identify the cause of the compliance breach as outlined in previous chapter.
In the case where the position of a specific noise on site is known, and the interest is to document the environmental impact of this source, Alerts can be limited only to those instances where there are high noise levels at multiple noise monitors. Thus, if one has a noise monitor close to a site, this can be used to indicate noisy activity due to specific sounds at that site. Considering sound propagation delay, high noise levels at a more remote noise monitor can be

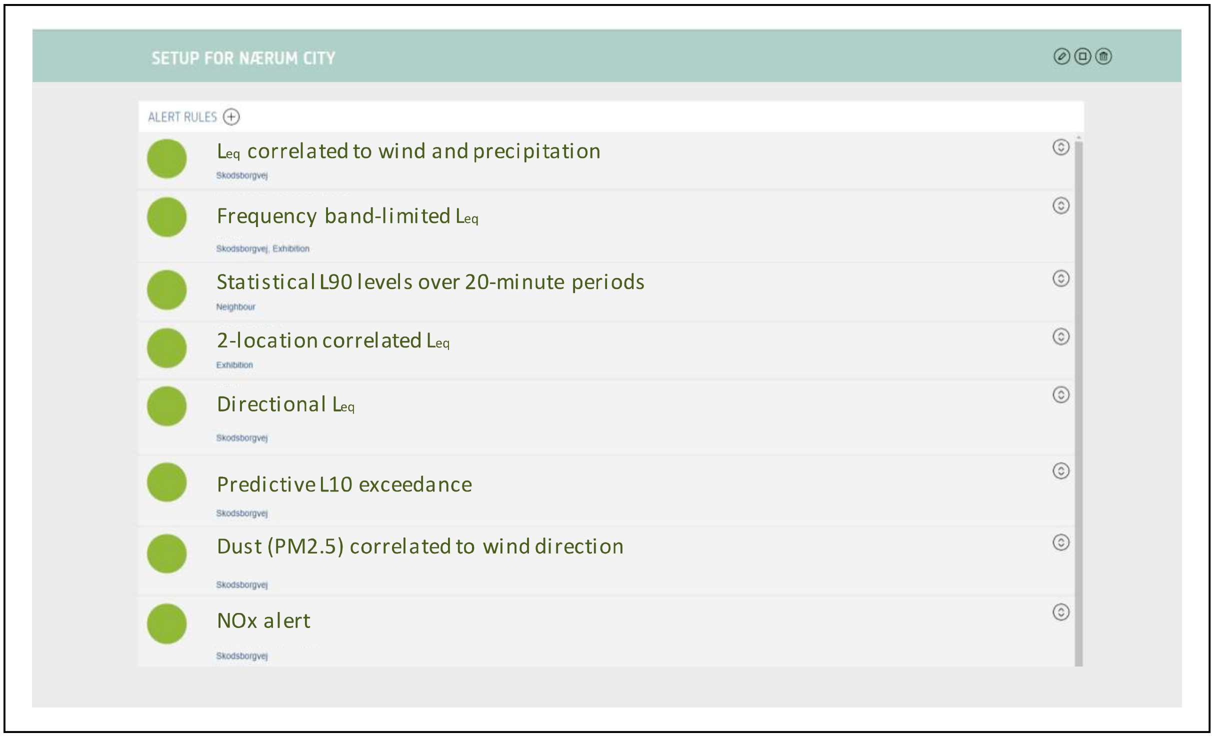

Figure 5. Examples of how to characterize different types of Alert rules [8].

filtered to only cause Alerts in instances where the levels at the other, closer proximity location also have been high. Thus, the actual levels at the compliance location are documented.

Potentially, the frequency content of the noise source is well-known and, if deviating from the residual noise, Alerts can be characterised within specific third octave bands, excluding all other frequency content of no interest.

Predictive Alerts can also be provided to warn of potential future compliance breaches. An example of this is if the compliance limit is an hourly L_{A10} level, then the L_{A10} level can be checked at e.g. 5-minute intervals and a Warning issued when the levels over the 5-minute intervals and the current hour are such that continuation of this operational state would cause a breach Alert, enabling the operator to react in a timely manner.

All the different type of Alert rules described in the above can be combined and tailored to the specific site and surroundings to exclude unrelated, residual noise in the comparison to thresholds. Examples of how to characterize different types of Alert rules [8] are listed in Figure 5.

4.4. Future developments

Input to the data correlation and detection of Alerts, is developing from conventional types of primary monitoring data to incorporating innovative and robust usage of new types of secondary data to increase environmental intelligence. Secondary data are characterised as data supporting the detection of alerts and determination of specific noise, but not, unlike primary data, applied as basis for evaluation of the compliance to relevant legislation.

New developments within the area of secondary data types include the implementation of real-time SCADA information, GPS tracking, video signals etc.

Future developments envisioned in specific noise determination incorporate other emerging technologies. As an example, an interface to fleet management software displaying the location and operation of construction vehicles and equipment in real time by GPS tracking could bring clarity to which specific source is the cause of a compliance breach – both in real-time and for historical data.

In cases where an application programming interface to SCADA information or GPS tracking software are not feasible due to inaccessibility or low-quality data, a noise indicator unit could prove its worth. A noise indicator unit is a low-cost noise monitor, that can be located at specific noise sources of interest. The intention of the noise indicator is not to document a precise noise level, but instead to log the operating condition of one specific source in relation to its noise emission and movement and to provide relative data (i.e. change in level). That information is then correlated to primary data from nearby monitors and forms the basis for a specific noise determination and effective Alert rules. By including GPS in the unit, mobile sources can be tracked, providing additional means to analyse causes of high noise levels in the community.

Another fresh technology that complements the monitoring concept and improves the ability of specific noise determination, is real-time image processing of video signals. By implementing image processing, the presence and motion of a moving object can be tracked by particular shapes or colours occurring in the video frames. Also, counter functionalities of multiple sources, e.g. road traffic counters, is an add-on that can be useful to aid source recognition and refined Alerts.

The computer science of machine learning has the potential to integrate algorithms of artificial intelligence into environmental monitoring, recognising patterns and regularities in data with the purpose to develop an automated and higher-level Alert classification; particularly when the investigated source is identifiable in a repetitive manner and associated with distinct content of energy, frequency distribution, recurrence etc. The infinite opportunities of pattern recognition have been driving the attractive mindset for decades, but so far without any large-scale implementation in environmental management. Too high uncertainties of recognised patterns detected in isolated data from individual monitors have led to an unstable outcome. The technology usually requires a considerable amount of input data together with the necessary computational power associated. Those premises seem to be fulfilled with the current setup of modern monitoring systems, where real-time data is flowing in from a far-reaching sensor network and processed on a central server. Automated alert classification based on pattern recognition can now be supported by data from sensors at different locations and other data types, upscaling the data pool extensively and reducing uncertainty of incorrect classifications. An example where automated Alert classification could benefit from pattern recognition is in relation to the noise exposure from blasts in mining operations. A rule

for pattern recognition based on the detection of a blast sound signature at one or potentially several noise monitoring terminals simultaneously and supported by data from a nearby blast overpressure monitor, could more robustly classify a blast.
In some instances, a reliable and robust pattern recognition will require an initial site-specific calibration period where the Alert classification are being done manually for some predefined types of noise sources [8] as illustrated in Figure 6, thereby building up a labelled set of "training" data. When the uncertainty of recognised patterns drops below a specified acceptance criterion, the automated functionality can take over and only in cases where an Alert is not fully recognised, classification is left to the operator by the predefined classifications or potentially a free-field text.
If robust enough, pattern recognition not only frees up operator time, but also makes it possible to automatically report corrected levels e.g. time-averaged noise levels by subtracting the residual noise energy during the identified event, thus increasing the quality of data.
The incorporated ability of pattern recognition in an environment management system would open up for stronger predictive functionalities where daily procedures, monthly tendencies etc. could be estimated. Such estimates would be very valuable in planning of workflows, site preparation of mitigation measures and for preparing community information to adjust expectations to the upcoming environmental impact.
Similar predictive functionalities could be obtained by the incorporation of more traditional predictive calculation models already prepared in the initial project phase, e.g. noise models, traffic models etc. Besides increasing the intelligence of the environment management system, a model cooperation can be used for returning monitoring data to the predictive calculation model for calibration purposes.

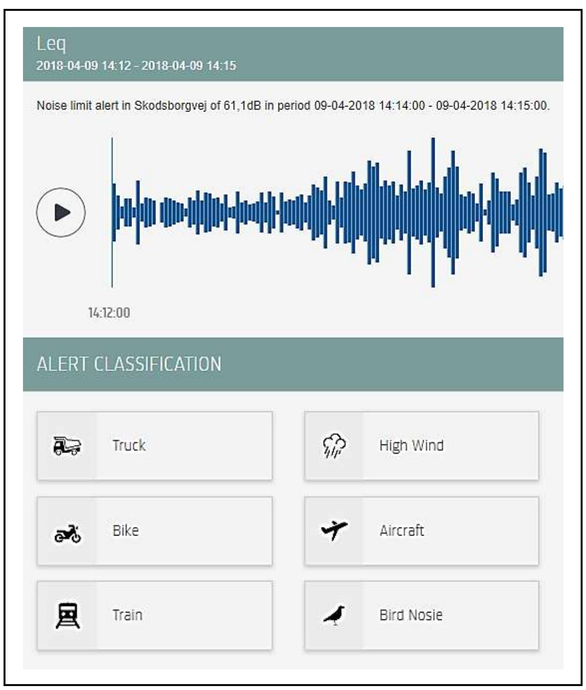

Figure 6. Predefined types of noise sources for manual classification [8].

5. Summary – The benefits of Alerts

Noise events work well where you have lots of discrete disturbances such as individual aircraft departures. However, if the disturbances under consideration are of more continuous character such as in an operating mine, noise events are not a very strong tool for picking out relevant specific noise sources. Alerts are more fit for purpose because they provide greater flexibility and more effective use of available information. Instead of predefining an event from a selected subset for processing and discarding everything else, Alerts take account of all information and detect data correlations of interest. Alerts are, of course, still provided immediately when certain levels exceed defined criteria enabling the operator to take instant action when the breach is occurring. In addition, predictive alerting enables owners to act on potential problems that may occur in the future, enabling them to maintain compliance. Alerts is a flexible approach that improves determining whether noise limit exceedances are due to specific noise from the operator and minimizes the number of false positives thus reducing the time the operator addresses these. In combination with secondary types of data and emerging technologies, Alerts enables automated operational management for optimal operational utilization of the environmental capacity.
The major drawback is the need to be connected to a server for server-side processing, but server-controlled systems are the norm today, and this is not seen as a significant disadvantage in practice.
Alerts are an integral part of award-winning noise management systems such as Sentinel [8], [10] for reducing noise pollution and thereby improving the surrounding environment. Because of the above reasons, the Alert concept is beginning to become more widely used.

6. Conclusions

Continuous, unattended noise monitoring systems can immediately alert you should noise levels exceed defined criteria. Once alerted to an exceedance, operators can act to return levels to compliance. The noise event technique has been widely used in combination with data from other systems in airport noise management systems for efficient noise management. For industrial applications, another approach is required due to the often-complex noise climates. This has led to the development of the Alert concept.
Using the Alert concept, operators can take proactive action to prevent breaches occurring, thus helping them to maintain compliance. In addition, the Alert concept can better separate specific sound from residual sound, reducing the number of potential false positive noise limit exceedances that need to be investigated and documented, thus reducing the time operators need to use.
The Alert concept is now successfully in use in several waste recycling plants, construction sites, mines and ports and is part of award-winning noise management solutions.
Future work to further develop the Alert technique into an even more powerful environmental management technology is identified in this paper.

7. References

[1] Acoustics — Description, measurement and assessment of environmental noise — Part 1: Basic quantities and assessment procedures. ISO 1996-1:2016

[2] D. Manvell & P. Stollery, "New techniques to determine specific noise for increasing the effectiveness of continuous unattended noise monitoring systems", *Proceedings of Internoise 2014,* Australia, 2014

[3] Acoustics — Unattended monitoring of aircraft sound in the vicinity of airports. ISO 20906:2009

[4] Product Data Sheet, Noise Monitoring Terminals Types 3639 and 3655 (BP2379-15); https://bksv.com/media/doc/bp2379.pdf; Brüel & Kjær Sound & Vibration Measurements A/S, Denmark 2013

[5] WebTrak, http://www.emsbk.com/webtrak/; EMS Brüel & Kjær, Denmark

[6] TraVis, https://topsonic.aero/en/aircraft-noise-flight-track-monitoring-system.html; Topsonic, Germany

[7] http://en.wikipedia.org/wiki/SCADA

[8] Product Data Sheet, Sentinel: Noise, Vibration, Dust and Air Quality Web-based Monitoring and Management (BP2389-15); https://bksv.com/media/doc/bp2389.pdf; Brüel & Kjær Sound & Vibration Measurements A/S, Denmark, 2016

[9] Product Data Sheet, Sentinel Directional Noise Monitoring (BP2488-11); http://bksv.com/doc/bp2488.pdf; Brüel & Kjær Sound & Vibration Measurements A/S, Denmark 2013

[10] John Connell Awards 2012 http://noiseabatementsociety.com/john-connell-awards/johnconnell2012/; Noise Abatement Society, UK 2012.