DEVELOPMENT OF CRITERIA TO MINIMIZE NOISE ANNOYANCE FROM INDUSTRIAL APPLICATIONS

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Abstract

Much of the developed world is continuing to undergo significant industrial growth. This naturally creates conflicts in land use resulting in competing interests between affected parties. Specifically, industry is looking for an attractive site near available infrastructure, and people are seeking a sedate country life offering more peace and quiet than most urban locations. Using current peer reviewed psychoacoustic and human health research, this paper will examine what noise level can reasonably be tolerated by individuals living in a rural environment and use this information in an attempt to define "noise annoyance" as it relates to industrial applications. Also discussed are the difficulties in trying to quantify any related health affects associated with noise annoyance. The result of this work is a proposed a set of criteria the authors offer as a reasonable way to accurately categorize noise annoyance. Finally this paper will offer industrial operators a practical approach including target sound pressure limits that should serve to ensure noise annoyance from nearby residents to industrial applications is far less likely to occur.

1. Introduction

Industrial noise generated from stationary sources (i.e. chemical or fertilizer production plants, refineries, asphalt plants, gravel crushers, manufacturing facilities, factories, electrical power plants, natural gas processing plants, pipeline compressor or pumping stations, etc.) can affect people in many different ways depending on a number of key variables. This paper considers health impacts due to annoyance to nearby residential neighbours (extra-auditory effects) and not on site workers (auditory effects). The effects of noise on workers (Occupational Noise) are more clearly understood and therefore widely regulated. Noise emissions from stationary sources to the environment pose the greatest challenge to regulators and industry specifically in establishing and maintaining appropriate limits.

The World Health Organization defines health as "a state of complete physical, mental, and social well-being, and not merely the absence of disease or infirmity." Health Canada accepts this definition and therefore considers noise to be a potential health hazard.

Noise is generally viewed as one of a number of general biological stressors. It is felt that excessive exposure to noise might be considered a health risk as noise may contribute to the development and aggravation of stress related conditions such as high blood pressure, coronary disease, ulcers, colitis, and migraine headaches. Loud sounds, such as impact noise and explosions, can cause an arousal response in which a series of reactions occur in the body. Adrenalin is released into the bloodstream; heart rate, blood pressure, and respiration tend to increase; gastrointestinal motility is inhibited; peripheral blood vessels constrict; and muscles tense. On the conscious level we are alerted and prepared to take action. Even though noise may have no relationship to danger, the body will respond automatically to noise as a warning signal. Research suggests that many of the reactions to a one time exposure of loud sounds are temporary in nature and will not result in any irreversible effects for the vast majority of the population, but there are some that would respond otherwise. For this to be the case, it is likely a result of pre-existing conditions.

The difficulty is in trying to correlate the biological stressor to some form of metric to determine "excessive exposure". One obvious approach used in exposure effects would be to quantify noise levels into "dose response" criteria. This would be consistent with other health criteria related to exposure from hazardous or toxic substances. Unlike these other substances, environmental noise is not always present, sound pressure levels varies significantly at the receptor, and affects to different individuals can be extremely varied based on non-physiological factors such subjectivity, relationship with the noise generator, and other expectations.

What we do know about noise and health effects is that there is a clear relationship. What is not clear are the levels that many of these conditions begin to manifest themselves in individuals. For example, there is growing evidence suggesting a link between noise and cardiovascular problems. There is also evidence suggesting that noise may be related to birth defects and low birth-weight babies. There are also some indications that noise exposure can increase susceptibility to viral infection and toxic substances. What we do not have is definitive sound pressure levels that can reliably be used to predict specific corresponding health impacts.

In the case of noise in the environment, the sound pressure level at receptor points (such are residences) are significantly dissipated in comparison to the SPL at the stationary industrial source. The SPL at the receptor point would be well below those levels where hearing loss would be a consideration and would generally not contain loud impact noise (i.e., explosions, blasts, etc). The SPL could, however, result in some degree of annoyance to the receptor if it is perceivably audible above the average ambient sound level for the receptor location. Consequently it will be necessary to examine what is noise annoyance, how does it affect people, why it is difficult to quantify, and are there some general criteria that can be used to categorize it.

2. What is Noise Annoyance

A classical definition of annoyance is "to be tormented or disturbed especially by continued or repeated acts, to tease, vex, pester or molest" Annoyance type reactions to noise and the effects it has on our health, excluding physical hearing loss, are called "extra-auditory" effects. These include stress, sleep disturbance, and quality of life aspects such as interference with speech, the body's physical reaction, and effects on our relations with other people. Stress due to noise is

closely related to both annoyance and the psychological reactions of the body. Annoyance probably influences the nervous system. In some people this influence may reach a point where physiological stress contributes to ill health. Annoyance is a very common reaction to noise and has important psychological ramifications. It is probably the most pervasive extra-auditory effect with respect to complaints by people about noise in the environment. A high level of annoyance is one of the criteria for judging the severity of the effects of noise, especially in a community setting. Annoyance is a psychological effect that is subtle and difficult to quantify, yet inescapable.

Annoyance to noise depend on several factors. First, the characteristic of sound strongly influences our perception of how noisy it is. For example, a low frequency or tonal component can often cause greater annoyance. Second, unappealing and frightening noise sources which can also produce annoyance reactions. A third factor is people's attitudes towards a noise source. The connotation of a noise may cause greater annoyance than its physical characteristics alone. Motorcycles for example are a major source of complaints about traffic noise. This reaction may result in part from a general negative attitude towards motorcycles and their riders.

Another factor is related to the expectation people have to a particular soundscape. Rural residents for example are accustomed to a generally quiet environment and may react strongly to and be annoyed by noisy intrusions that urban residents might readily accept. People at home usually expect conditions to be quieter at night than during the day and are more annoyed with noise at night. Therefore, assessing annoyance due to noise is very complex. It involves the characteristics of the noise, the way noise affects people's expectations and attitudes, and the social and economic conditions and influences in a person's life.

3. Facts about Environmental Noise

Firstly, environmental noise at a receptor location differs from workplace noise in that it is generally intermittent, covers some portion of the 365 days in a year rather than 250 work days, and covers 0 - 24 hours per day rather than 8 - 12 hours. Taking these factors into account, some research has identified a noise level at the ear of less than L_{eq} (24hr) = 70 dB will protect 96 percent of the general population from a hearing loss of greater than 5 dB at 4000 Hz. (Note: The 96 percentile estimate does not take into consideration the amount of hearing damage when the control, non-exposed population is subject to high levels of non-occupational noise. Thus, the 70 dB protective level is simply the best present estimate, subject to change if better data become available.)

What this means to residents living near an industrial facility is that given the current regulatory requirements for environmental noise used in Canada today, hearing loss is not even a remote possibility. Although criteria have not been established at the present time for agencies that regulate annoyance, the United States Environment Protection Agency has stated that noise levels identified to protect against hearing loss should be sufficient to protect against the non-auditory effects of noise. However, in considering noise as a general stressor, the need to establish criteria for noise annoyance is rather obvious with the growing concern about these effects.

As for health effects associated with community or environmental noise exposures, several field studies have examined health outcomes as a function of exposure to traffic and aircraft noise at levels equivalent to 55 - 75 dBA. Although these studies must be viewed as exploratory rather than confirmatory, evidence has been obtained for increased rates of hypertension and cardiovascular disease, and increased subjective and self-reported symptoms and complaints. These studies suggest the possibility of adverse health outcomes associated with some environmental noise and it can be reasonable assumed that, although much different than traffic or aircraft noise, similar results may be present for people living near industrial facilities exposed to the same levels of noise. Depending on the individual noise may aggravate an existing health problem such as heart disease, high blood pressure, and emotional illness and these people may need protection from the additional stress of noise. However, no research exists to document this area of concern.

While a growing body of evidence, provided and accepted by a growing number of scientists, suggests that noise can be considered a general biological stressor, not all findings and not all scientists agree. One researcher performed studies in which his subjects demonstrated relatively small physiological changes in response to noise. This researcher believes that the acoustic-vascular response to noise can be explained by a protective auditory condition that results in a non-stressful sympathetic nervous system reflex. He considers this to be a transient physiological change observed after noise exposure rather than the expected stress response generally assumed to be responsible for a permanent or long term health impact. So there are differences in scientific opinion about both the mechanism by which noise affects the body and the degree to which these effects are stressful. Many of these differences may eventually be explained in terms of the distinct ways in which two different individuals may respond to an identical stimulus.

4. Non-auditory Physiological Response

While it is generally believed that there is no health risk from short term exposure to noise because the body has a chance to recover. A little stress, as many people will attest, may be beneficial. There may be exceptions; for example, it is possible that repeated or constant exposure to noise can contribute to deterioration in health. Whether or not environmental or industrial noise by itself can lead to health effects is hard to determine since there are so many other stresses to which people are exposed. This research is difficult to conduct and little has been done in this area. The research that has been conducted is growing and suggests a relationship between some long-term noise exposures and stress-related health effects. Physiological responses (bodily reactions) as part of a general stress response are triggered by impulses from the brain activate centers of the autonomic nervous system. Systems that may be affected include the glandular, cardiovascular, gastrointestinal, and musculoskelatal systems. Probably the most significant contributor to a stress response due to annoyance from industrial noise for nearby residents is the formation of a sleep disorder or sleep disturbance.

Sleep disorder is a disruptive pattern of sleep that may include difficulty falling or staying asleep, falling asleep at inappropriate times, excessive total sleep time, or abnormal behaviors associated with sleep. Noise typically affects sleep at roughly 30 decibels, or about the background noise

from an air conditioner. The louder or more frequently noise occurs, the worse one's sleep will be.

Sleep disturbance is one of the major causes of annoyance due to noise. If it becomes a chronic problem, sleep disturbance may potentially lead to health disorders. Noise, of course, can make it difficult to fall asleep. Noise levels can create momentary disturbances of natural sleep patterns by causing shifts from deep to lighter stages. Noise may even cause awakening which the person may or may not be able to recall.

At levels of 40 to 50 dBA, some subjects have reported difficulty in falling asleep, frequently taking over an hour. The number of subjects having difficulty increases as the sound level increases. Studies have shown that at levels of 70 dBA or above, behavioral awakening will most likely occur. The temporal pattern of exposure (i.e., short or long duration) has a major effect on awakenings due to noise. Short signals have to be much higher in level to awaken people as a longer, steady noise.

Not all sounds of the same level are equally capable of awakening people. The character of some sounds causes more people to awaken than other sounds at the same level. People living in higher background noise neighborhoods tend to awaken less than people living in quieter background noise neighborhoods.

The awakening effects of noise appear to be related to the time of occurrence of exposure during the night. The probability of awakening to noises of the same level is slightly lower within two hours after retiring than when it occurs later in the night. A person typically goes through a cycle of sleep which becomes progressively deeper, and the stages of this cycle may vary in length of time. These stages are reflected in physiological effects such as heart rate changes, vasoconstriction, respiration changes, electrodermal activity, and motor responses which are all sensitive to noise during sleep.

As seen in Figures 1 and 2. (adapted from a summary and analysis of recent experimental sleep data related to noise exposure) there is a relationship between frequency of response (disruption or awakening) and the sound level of an intrusive noise. In Figure 1, the frequency of sleep disruption (as measured by changes in sleep stage, including behavioral awakening) is plotted as a function of the Sound Exposure Level. Similarly, the frequency of awakening is shown in Figure 2. From these figures it is possible to predict the probability of sleep disturbance at a certain sound exposure level.

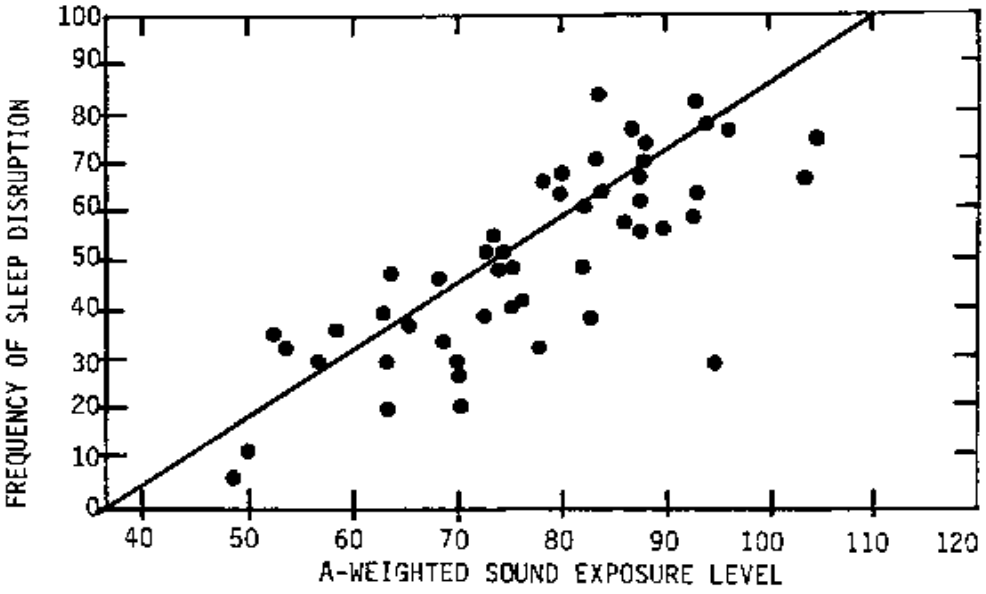

Figure 1 Probability of a noise induced sleep stage change.

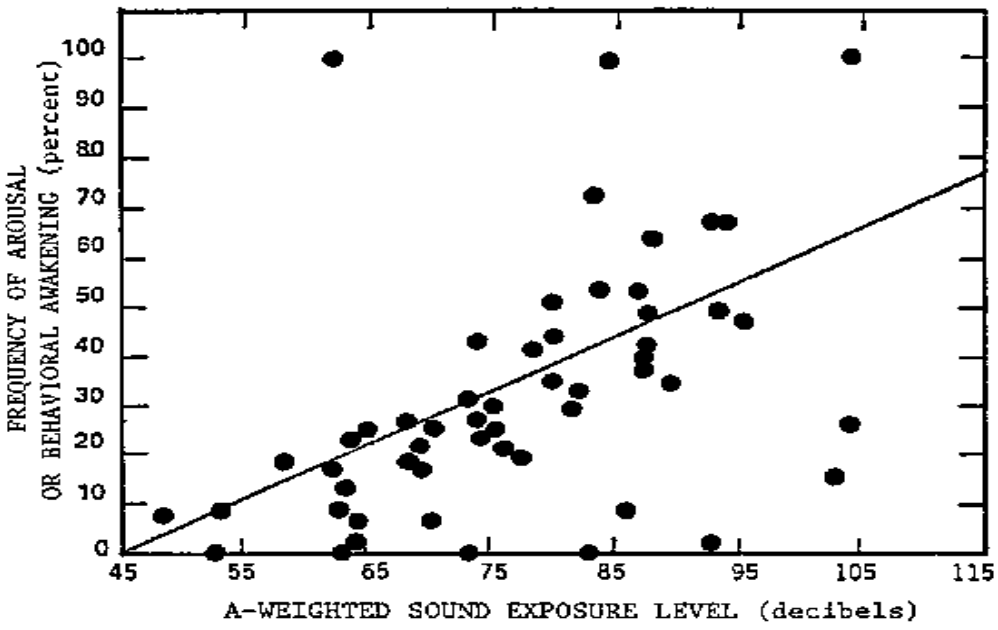

Figure 2 Probability of a noise induced awakening.

Generally, the higher the noise level the greater the probability of a response. Researchers found that there was a 5 percent probability of subjects being awakened by peak levels of 50 dBA and a 30 percent probability at 70 dBA. If the number of sound peaks increases, the person will take longer to fall asleep even if the average sound level decreases. However, continuous or very frequent noise throughout the night, even as high as 95 dBA, appears to cause little change in the

average duration of the sleep stages. This occurs because disturbances to sleep stages are more likely to be caused by sound peaks that vary widely from the background ambient level than by high continuous levels alone. Inherently meaningful sound, such as one's name or sound that acquires meaning by instructions or conditioning, can awaken a sleeper at lower intensities than those required for meaningless or neutral sounds. Also, unfamiliar sounds may awaken people at a lower level than familiar ones.

Several investigators have reported that middle-aged women may be less sensitive to noise during sleep. In general, the older the subject, the more likely he is to respond to noise while sleeping. Young children, on the other hand, appear to be less affected by noise in all stages of sleep.

Table 1 below presents information on the possible effects on people caused by outdoor noise levels of 55 dBA. By extrapolation there will likely be less effects at lower sound levels.

Table 1. Summary of Human Effects for Outdoor Sound Level of 55 dBA

Type of Effect	Magnitude of Effect
Hearing Loss	Will not occur
Risk of non-auditory disease (stress)	Research implicates noise as a potential factor producing stress-related health effects such as heart disease, high blood pressure and stroke, ulcers and other digestive disorders. However, the relationships between noise and these effects have not yet been quantified.
Speech Indoors	No disturbance of normal conversation. 100 percent sentence intelligibility (average) with a 5 dB margin of safety
Speech Outdoors	Slight disturbance of normal voice or relaxed conversation with - 100 percent sentence intelligibility (average) at 0.35 meter, or - 99 percent sentence intelligibility (average) at 1.0 meter, or - 95 percent sentence intelligibility (average) at 3.5 meters.
High Annoyance	Depending on attitude and other non-acoustical factors, approximately 4 percent of the population will be highly annoyed.
Overt Community Reaction	None expected; 7 dB below level of significant "complaints and threats of legal action," but at least 16 dB below "vigorous action" (attitudes and other non-acoustical factors may modify this effect)
Attitudes Towards Area	Noise considered no more important than various other environmental factors

5. Subjective Response

Conclusions concerning the factors that determine an individual's subjective, psychological response to noise are difficult to derive since individuals vary so much in their reaction to noise. Clearly, more research is needed to assess this complex topic fully.

Excessive noise exposure can bring about a wide variety of psychological responses or symptoms in the individual. A person may respond with anger, or experience symptoms such as anxiety, irritability, and/or general emotional stress. Distraction and poor judgment may result from mental fatigue.

The physical attributes of noise that can affect an individual's subjective response include: apparent loudness or intensity, spectral shape, presence of discrete frequency components, abruptness or impulsiveness, intermittency, duration, and temporal variations.

Among the factors that affect an individual's response to noise are contextual factors such as: the time of day, the activity interfered with, the ability to control the source, and the information content of the noise. Response may also be affected by personal factors such as previous experience with noise exposure or socio-economic and educational status.

With respect to industrial noise at or inside a residence low frequency noise of 250 KHz or lower (especially those with discrete frequency components) are generally the most annoying and disruptive, although noises that are abrupt, intermittent, or fluctuate with time can be very annoying as well. In general, the louder the noise the more annoying it is likely to be.

6. Categorizing Annoyance

Based on the scientific information and findings it can be reasonably hypothesized that annoyance from industrial noise is a result of many factors that can be grouped into two basic categories, “Technical” and “Psychological” as noted below:

Annoyance Technical Factors:

- Constant industrial noise levels that exceed 55dBA outdoors at a residence
- Sharp intermittent noise events
- Large swings in noise levels of at least 20dBA above ambient levels
- Low Frequency Noise content including tonal component

Annoyance Psychological Factors:

- Perception of loudness (just hearing it creates anger)
- Attitude toward the noise source (poor relationship with operator)
- Sense of no control over the noise (did not want it there)
- Fear of the noise source (associate explosion, toxic release, fire, etc.)
- Unappealing noise (may be low sound level but not pleasant or relaxing)
- Expectations of the soundscape (rural setting should be quiet, visually aesthetic)

Given that these factors would provide a basis by which to categorize under what conditions annoyance from industrial noise would likely occur the authors argue that the following construct would apply:

"Annoyance is a state of human emotion that will likely occur:

- *when there is a constant industrial noise level greater than55dBA outdoors at a residence or*
- *significant swings in noise levels that exceed the ambient sound level by at least 20 dBA, or*
- *when there are loud intermittent events, or when there is a clearly defined low frequency noise content, or*
- *when there is deep mistrust in the operator by nearby residents."*

As a barrier to development and meaningful community relations, industrial operators, acoustical consultant, and regulators must recognize that the planning and design phase of any project where noise is a consideration must address those factors that may lead to Annoyance.

From a control standpoint to minimize the potential for annoyance from industrial noise, it is necessary to first control the technical factors. In doing so, it is expected that the psychological factors will be less likely to manifest themselves. The following are recommendations in how to address the individual technical factors.

- Constant noise levels that exceed 55dBA outdoors

  According to the World Health Organization the recommended sound level for a bedroom should be approximately 30 dBA. This will ensure minimum sleep disturbance from a sound source. According to the Canada Mortgage and Housing Corporation, building construction standards should provide noise attenuation of approximately 20 dBA even with a window open. Consequently, the limit for industrial noise at a residence should not exceed 50 dBA Leq or 5 dBA Leq above the established ambient sound level, whichever is greater provided there is no low frequency noise component.

- Sharp intermittent noise events

  Loud events, such as steam releases, blowdowns, flaring, blasting, pile driving, backup warning signals, plant pubic address systems (PA's), alarm sirens, etc. are all considered as intermittent noise events. If these occur regularly on an unscheduled basis, especially during the night time period, high levels of annoyance will likely occur. The impact of these events should be assessed by the operator before they are a problem and mitigation implemented to minimize the potential impact on nearby residents. Operators should communicate well before any impending operations that may result in any intermittent events and schedule these during day time hours if possible.

- Large swings in noise levels above ambient levels

  Many residents become more aware of the industrial noise when there are large swings in the background sound level due primarily to atmospheric conditions. For example the sound level could go from 25 to 45 dBA in a few minutes for short durations of time if conditions for noise propagation are favourable. A 20 dB increase in sound level would be very noticeable and may even cause sleep patterns to be disturbed. This could be a source of annoyance especially if any of the psychological factors are at play.

- Low Frequency Noise content including tonal component

  As industrial noise travels in the atmosphere, much of the higher frequency sounds will decade quickly with distance. On the other hand, low frequency noise will tend to retain its sound energy over longer distances less affected by absorption by the air or ground. This has the potential, therefore, to remain strong in signal strength at a nearby residence and in some cases affect indoor sound levels more so than broadband noise especially if there is a tonal component. Operators should consider the potential for low frequency noise at the design stage for new facilities or to test existing facilities accordingly. One method to determine if there is a low frequency noise content is to conduct a survey at the residence(s) in question in both the A and C weighted networks. If the difference between the A weighted and C weighted measurements is greater than 20 dB "and" there is a clear tonal component in the frequency spectrum below 250 Hz., a low frequency noise problem probably exists. If this is the case, appropriate diagnostics should be undertaken to locate the source followed by effective noise mitigation.

In addition to addressing these technical factors, industrial operators should give meaningful consideration to several additional items that can in part address the psychological reaction to noise.

- Control in decision making

  The sense of feeling powerless to have any say in an industrial project that is being planned near their home is sometimes a very upsetting and emotional event. People often fear these facilities because of the perception that it will affect their health, safety, security, property values, livelihood, etc.. They often feel that they must bear the risk and yet receive no direct benefit from the project. Operators should be more cognizant of how the public perceives them and their industrial facilities as neighbours. They should work early in the project concept stage to bring the local residents into the decision making process and give them a real sense of having some control. There is a rich library of Risk Communication literature and training that will help industrial operators to understand how to conduct effective pubic consultation and involvement programs that will result in confident and trusting relationships.

- Visual aesthetics

  The old adage “out of sight out of mind” is quite valid especially when dealing with the subjective nature of perceived loudness of a facility. According to residents living near the facility in the photo below “they are not even aware that it is noisy as they just don’t think about it”. When something looks relatively the same as what we have (in this case a house and barns), people tend to mirror with the site. That is it looks like ours as seen in a mirror, and we are not noisy so it registers in the psyche as normal and acceptable. Given that facilities like these, where an operator has taken extra measures to address the visual aesthetics, one can be reasonably certain that the same care and consideration went into the noise control equation. The design and construction of these eye pleasing and landscape friendly buildings resulted in only a 10% premium to the original cost of typical industrial style buildings.

(Photo provided courtesy of Shamen Energy, Calgary, Alberta)

7. Conclusion

When it comes to health effects related to noise annoyance levels it is clear that these are very difficult to quantify given the many factors that influence the outcome. By understanding both the Technical and Psychological factors that affect "Annoyance" we are able to categorize the parameters that must exist for it to manifest itself in those living near industrial facilities. Addressing the Annoyance factors meaningfully in the planning, design and operational stages, will help to minimize Annoyance from occurring in the first place and secondly provide the foundation for a lasting relationship between the operator and their neighbours built on mutual trust and respect.

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