CURRENT STATE OF RESEARCH AND KNOWLEDGE REGARDING ACTIVE NOISE CONTROL (ANC) TECHNOLOGY

ROAD TRAFFIC NOISE: HOW ITS CONTROL AND REGULATION AFFECT SOCIETY

A Thesis Prospectus
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By
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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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In general, noise is not publicly perceived as a major threat to be concerned about, especially when compared to other major forms of pollution such as air, water, and even light (Oguntunde et al., 2019). However, research has proven that noise and its risks should be looked at more in depth, such as its adverse effects on individuals' health when they are exposed to higher decibel ranges. According to the U.S. Environmental Protection Agency ("Clean Air Act Title IV – Noise Pollution", 2021), excess noise can cause "stress, high blood pressure, speech interference, hearing loss, sleep disruption, and lost productivity" (Health Effects section, para. 1). Along with the health risks, the scale that the public is exposed to high noise levels is also a major concern. For instance, according to an EPA report authored by Simpson and Bruce, in 1981, roughly half of the U.S. population at the time, about 100 million people, were reportedly exposed to levels of road traffic noise on a yearly basis that negatively impacted their health and well-being (as cited in Hammer et al., 2013).

The problem of noise, specifically regarding the reduction of higher decibel levels, will be looked at more in depth through the technical research and tightly coupled STS research. The technical research will look at the current state of research of Active Noise Control (ANC), a technology that inputs surrounding noise with a microphone and through the use of an algorithm produces an inverse wave from a speaker that either cancels out or dampens the originally sourced noise (Elliott and Nelson, 1993). While ANC technology provides one possible solution to excess noise, it must be noted that these possible solutions can have diverse effects on various societal factors. Thus, the STS research will focus on the problem of road traffic noise as well as the impacts that its control and regulation have on society. The technical side of the research will be started and completed during the Fall 2022 semester while the STS research will be started and completed the following semester, Spring 2023.

CURRENT STATE OF RESEARCH AND KNOWLEDGE REGARDING ACTIVE NOISE CONTROL (ANC) TECHNOLOGY

Many technologies that have been developed and are used in today's society produce noise. However, often times, many of these devices exceed what is considered a safe listening level. The loudness of noise that is generally deemed as safe for exposure of long periods of time is anything below 70dB ("Too Loud. Too Long.", 2019). Thus, exposure to noise greater than 70dB is considered to be dangerous and can have negative consequences on individuals' well-being such as the development of hearing loss and/or an increase in blood pressure among other health risks ("Loud Noise Dangers", n.d.). As seen in Figure 1, technologies that people are exposed to on a daily basis such as cars, trucks, and hair dryers produce levels of noise that are considered unsafe. Thus, research into noise control technologies is imperative as technology becomes more established into one's day to day life.

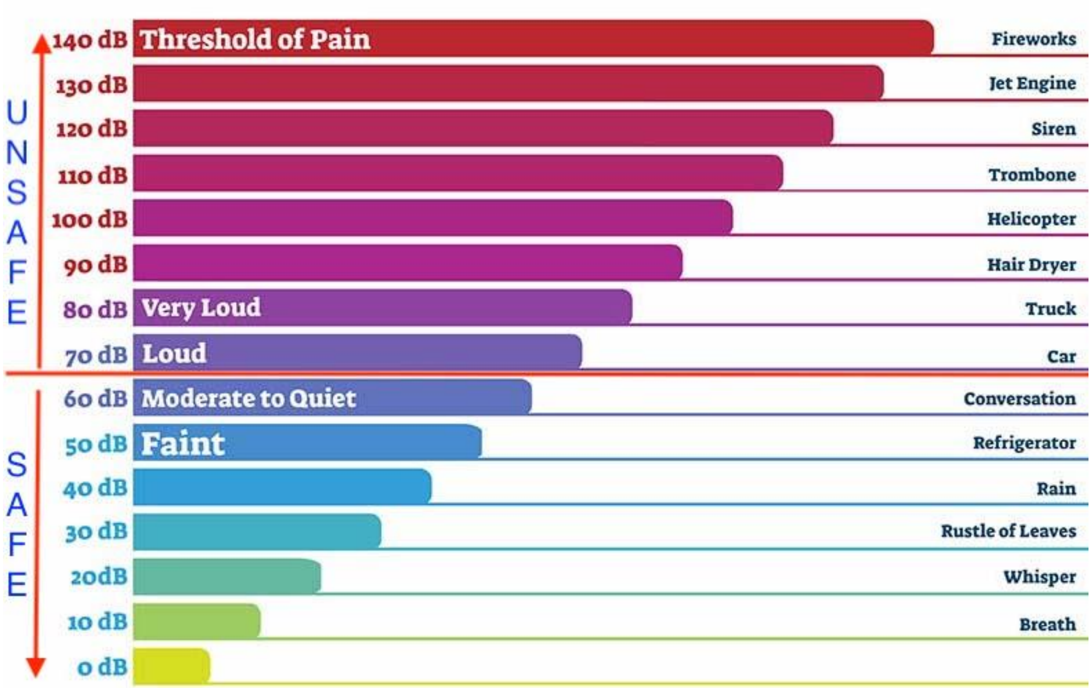

Figure 1: Common Technologies' Decibel Level. The visual depiction of the noise levels of various technologies and whether they may be considered to be safe or unsafe for listening. (Adapted by Kyle Kuennen (2022) from "Sound Level Examples" n.d.).

There are two main ways in which noise levels can effectively be reduced, Active Noise Control (ANC) and Passive Noise Control (PNC). Passive Noise Control uses physical barriers to block/reduce noise such as insulation or foam pads (Kajikawa et al., 2012). However, there are downsides to PNC technology, thus not allowing it to be applicable in every situation. Specifically, PNC is not effective at blocking noise that are of lower frequencies. Additionally, some other limitations of PNC include the possibility of airflow being restricted as well as often times these physical barriers being heavy in weight (Lam et al., 2021). Comparatively, ANC systems have been seen as being able to effectively block lower frequencies**.** Additionally, as they are not physical barriers, they are often lightweight and allow unrestricted airflow (Lam et al., 2021). With PNC systems not being effective in every situation, this shows the significance behind the research of ANC technology to ensure sound is able to be reduced in all applications when needed.

The objective of this research work is to look at the current state of knowledge of ANC technology. Various aspects of ANC will be studied and considered through the literature review of related works. The history and the foundations of ANC technology will be discussed in order to provide background information on the topic. The technology itself and how it works will be looked at, and, more specifically, the algorithms that are employed in these systems such as the most commonly used algorithm in ANC systems, the Filtered-x Least Mean Square Algorithm (Yang et al., 2018). Additionally, ANC technology’s current applications will be reviewed such as ANC being incorporated into automobile and airplane cabins, headphones, household appliances, and even certain interior spaces (Miljković, 2016). The current limitations of ANC will be examined, such as its inefficiency at higher frequencies and open spaces (Lee et al.

2019), as well as the research being done to overcome these limitations. Finally, the possible future applications of ANC technology that are currently being studied will be explored in depth.

This project will be researched and compiled into a comprehensive state of the art report during the Fall 2022 semester. The anticipated outcome of this research will be to gain a greater understanding regarding the significance of ANC technology as well as the potential benefits it can bring to reducing loud noise levels especially with "noise pollution impact[ing] millions of people on a daily basis" ("Noise Pollution", 2022, para. 3).

THE IMPACT OF ROAD TRAFFIC NOISE ON INDIVIDUALS

In 2021, there were roughly 290 million automobiles registered in the United States, roughly a 1% increase in the amount of cars compared to the year before with this trend reoccurring with the years prior ("The Number of Cars in the US in 2022/2023: Market Share, Distribution, Trends", n.d.). As the number of automobiles that are on the roads increase it is important to consider the noise levels that they produce. According to Corbisier of the U.S. Department of Transportation (2003), cars and trucks average around 70-80 dB, which are considered unsafe levels, when listening from only fifty feet away. Thus, while it is clear that cars and trucks produce unsafe noise levels, it is almost important to note the amount of people that are being exposed the road traffic noise. According to World Health Organization (as cited in Ugay et al, 2013), 60-80% of European citizens are exposed to noise caused by road traffic at levels during the daytime being between 70-90dB. Thus, well over a majority of European citizens are affected revealing how widespread this problem is.

The problem of road traffic noise is also of great significance due to its impact on an individual's health and well-being. According to Munzel et al. (2020), "Traffic noise has been classified as the second worst environmental stressor affecting human health, exceeded only by air pollution." (p.310) Additionally, Nazneen et al. (2020), through their studies regarding noise pollution in multiple Pakistan cities, highlight that traffic noise have many negative impacts of human health. The authors go on to state that road traffic noise can be linked with symptoms such as anxiety, hostility, sleep disturbance, headaches, and fatigue among others.

THE IMPLEMENTATION OF NOISE CONTROL AND REGULATION REGARDING ROAD TRAFFIC

There are three main elements of road traffic noise that must be considered which are depicted in Figure 2 on page 6: sound source, sound propagation, and the receiver of the sound (Rochat, 2016). Sound source with regard to road traffic can deal with the noise coming from the automobile's engine. However, there are other elements involved such as the speed at which the automobile is going, the density of traffic on a specific roadway, and even the type of pavement which all play a role in the source of road traffic noise. Sound propagation has to do with the path the sound takes from the source to the receiver. More specifically, whether there are any barriers or shielding put in place or lack of obstacles along the path. Lastly, the receiver of the sound refers to the individuals who are experiencing road traffic noise and their position relative to the roadways. Sound source, sound propagation, and the receiver of the sound all play a role in road traffic noise, and thus the implementation of noise control and its societal impact, whether economic, social, or political, needs to be considered for all three elements.

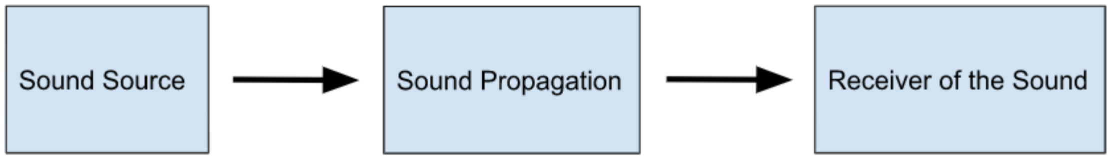

Figure 2: Elements of Road Traffic Noise. A visual representation of the three different elements of road traffic noise and how they are linked with one another. (Kuennen, 2022)

When regulating the sound source there are many options. One such option is to regulate the automotive manufacturers. Regulations imposed on these manufactures would require the automobiles they produce to not exceed standardized noise limits. This process however may have economic downsides. For instance, it is possible that due these requirements being put in place, the automotive manufactures would have to spend more money both on researching and building quieter cars. This may in turn lead to an increased upfront cost towards the consumer. Currently, some of the quietest cars are electric cars, however, on average an electric car will cost roughly $10,000 more up front compared to an average gas-powered car (Lindwall, 2022). Another possibility of regulating the sound source would be to fine those who exceed a set noise limit when driving on roadways. In France, noise sensors have currently been put in place that detect the noise coming from automobiles and if too loud take a picture of the license plate and fine the respective party (Bubola, 2022). However, this form of regulation has already received backlash from some groups, such as bikers, who feel the use of technology in that way is unfair.

The control of the path that sound travels from the roadway to the individual can also be regulated to effectively reduce excess noise. The regulation of sound propagation can be done primarily through the placement of barriers and shieldings between busy roadways and buildings/houses. However, the placement of these physical barriers needs to be considered with regard to whether there is an underlying inequality. Langdon Winner, proposes the idea that technology can have politics (Winner, 1980). One example he describes is with regard to the building of low bridges in New York:

> It turns out, however, that some two hundred or so low hanging overpasses on Long Island are there for a reason. They were deliberately designed and built that way by someone who wanted to achieve a particular social effect. Robert Moses, the master builder of roads, parks, bridges, and other public works of the 1920s to the 1970s in New York, built his overpasses according to specifications that would discourage the presence of buses on his parkways. According to evidence provided by Moses' biographer, Robert A. Caro, the reasons reflect Moses' social class bias and racial prejudice. Automobile-owning whites of "upper" and "comfortable middle" classes, as he called them, would be free to use the parkways for recreation and commuting. Poor people and blacks, who normally used public transit, were kept off the roads because the twelve-foot tall buses could not handle the overpasses (Winner, 1980, p.23).

Thus, it is evident that the building of public works, such as bridges or even noise control barriers, can have a political and social aspect attached to them. Additionally, supporting the notion put forth by Winner, there is data confirming that on average the noise produced both at night and during the day is comparatively higher in communities of nonwhite residents and/or lower socioeconomic status (Seltenrich, 2017).

Finally, there is the control of road traffic noise with regard to the receiver of the sound. Options for this include zoning and more in depth planning with regard to building living spaces away from busy roadways so that individuals are not in range of potentially harmful sounds. However, this is not always possible especially in well-established cities. It must also be noted that locations and living spaces that are close to busy roadways and experience road traffic noise have seen a devaluation in property value, such as in many French cities, as stated by Bubola (2022). Thus, there is again an inequality in individuals who are exposed to road traffic noise.

Through researching road traffic noise and the implementation of regulations and noise control systems, the societal impact these measures have will be looked at. The framework that will be used to accomplish this will be the Societal Construction of Technology (SCOT) approach as described by Bijker and Pinch (1984). This framework, as depicted in Figure 3, centers around the engineers, specifically those that design noise control technology. The engineer is then responsible for looking at how that technology may impact other societal groups. In this case, the engineer must understand the impact that the technology may have on the automobile manufactures, the drivers/owners of automobiles, government agencies, and individuals exposed to road traffic noise. It is not only important to discuss the immediate technical impact the technology may have on these groups but also look at potential economic, political, and social impacts as well.

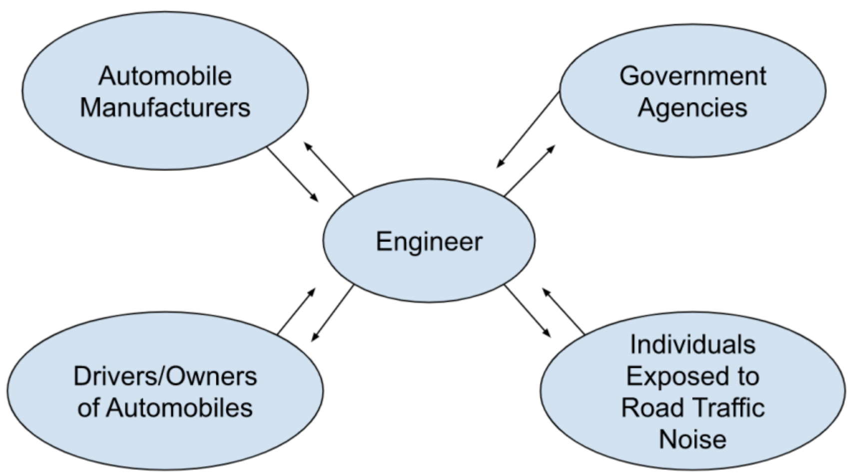

Figure 3: SCOT Analysis of Noise Control Technology. Visual depiction of the interaction between the engineer and other societal groups with regard to road traffic noise control. (Kuennen, 2022)

Overall, the goal of this research is to examine the significance that is the problem of road traffic noise as well as, through an STS lens, study the impact that noise control and regulations may have on various societal groups. This research will be compiled in the form of a scholarly article that will be completed during the Spring 2023 semester.

REFERENCES

AAA Audio Labs Ltd. (n.d.) Common Technologies' Decibel Level. [Figure 1]. *Sound Level Examples*. https://aaaaudiolab.com/page04.html

American Speech-Language-Hearing Association. (n.d.). *Loud Noise Dangers*. https://www.asha.org/public/hearing/loud-noise-dangers/

Bijker, W. E., & Pinch, T. J. (1984). The social construction of facts and artifacts. Social Studies of Science, 14(3), 399–441. https://doi.org/10.1177/030631284014003004

Bubola, E. (2022, February 21). With sensors on streets, France takes aim at 'noise from hell'. *The New York Times*. https://www.nytimes.com/2022/02/21/world/europe/france-street-noise.html

Corbisier, C. (2003). Living with noise. *U.S. Department of Transportation*. https://highways.dot.gov/public-roads/julyaugust-2003/living-noise

Elliott, S. J., & Nelson, P.A. (1993). Active noise control. *IEEE Signal Processing Magazine*, 10(4), 12-35. https://ieeexplore.ieee.org/abstract/document/248551/authors#authors

FinancesOnline. (n.d.). *The Number of Cars in the US in 2022/2023: Market Share, Distribution, Trends. https://financesonline.com/number-of-cars-in-the-us/*

Hammer, M. S., Swinburn, T. K., & Neitzel, R. L. (2014). Environmental noise pollution in the United States: developing an effective public health response. *Environmental health perspectives*, *122*(2), 115–119. https://doi.org/10.1289/ehp.1307272

Kajikawa, Y., Gan, W., & Kuo, S. (2012). Recent advances on active noise control: Open issues and innovative applications. *APSIPA Transactions on Signal and Information Processing, 1*, E3. https://www.cambridge.org/core/journals/apsipa-transactions-on-signal-and-information-processing/article/recent-advances-on-active-noise-control-open-issues-and-innovative-applications/9E27156562A24026ECD6F6A49A54F53A

Kuennen, K. (2022). *Elements of Road Traffic Noise.* [Figure 2]. *Prospectus* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Kuennen, K. (2022). *SCOT Analysis of Noise Control Technology*. [Figure 3]. *Prospectus* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Lam, B., Gan, W., Shi, D., Nishimura, M., & Elliott, S. (2021). Ten questions concerning active noise control in the built environment. *Building and Environment, 200*, 1. https://doi.org/10.1016/j.buildenv.2021.107928

Lee, H. M., Wang, Z., Lim, K. M., & Lee, H. P. (2019). A review of active noise control applications on noise barrier in three-dimensional/open space: Myths and challenges. *Fluctuation and Noise Letters*, *18*(04). https://doi.org/10.1142/S0219477519300027

Lindwall, C. (2022, May 25). Electric vs. gas cars: Is it cheaper to drive an EV? *NRDC*. https://www.nrdc.org/stories/electric-vs-gas-it-cheaper-drive-ev

Miljković, D. (2016). Active noise control: From analog to digital—Last 80 years. *2016 39th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*, 1151–1156. https://doi.org/10.1109/MIPRO.2016.7522313

Münzel, T., Kröller-Schön, S., Oelze, M., Gori, T., Schmidt, F. P., Steven, S., ... & Sørensen, M. (2020). Adverse cardiovascular effects of traffic noise with a focus on nighttime noise and the new WHO noise guidelines. *Annu Rev Public Health*, *41*(1), 309-328.

National Geographic. (2022, May). *Noise Pollution*. https://education.nationalgeographic.org/resource/noise-pollution

National Institute on Deafness and Other Communication Disorders. (2019, May). *Too Loud. Too Long.* https://www.noisyplanet.nidcd.nih.gov/parents/too-loud-too-long#:~:text=Decibel%20Level%E2%80%8B&text=Sounds%20at%20or%20below%2070,greater%20risk%20for%20hearing%20loss

Nazneen, S., Raza, A., & Khan, S. (2020). Assessment of noise pollution and associated subjective health complaints and psychological symptoms: Analysis through structure equation model. *Environmental Science and Pollution Research*, *27*(17), 21570–21580. https://doi.org/10.1007/s11356-020-08655-x

Oguntunde, P. E., Okagbue, H. I., Oguntunde, O. A., & Odetunmibi, O. O. (2019). A study of noise pollution measurements and possible effects on public health in Ota Metropolis, Nigeria. *Open access Macedonian journal of medical sciences*, *7*(8), 1391–1395. https://doi.org/10.3889/oamjms.2019.234

Rochat, J. L., & Reiter, D. (2016). Highway traffic noise. *Acoustics Today*, *12*(4), 38. https://acousticstoday.org/wp-content/uploads/2018/08/Highway-Traffic-Noise-Judith-L.-Rochat.pdf

Seltenrich, N. (2017). Inequality of noise exposures: A portrait of the United States. *Environmental Health Perspectives*, *125*(9). https://ehp.niehs.nih.gov/doi/full/10.1289/EHP2471

Simpson, M., & Bruce, R. (1981). Noise in America: The extent of the noise problem. *U.S. Environmental Protection Agency* (Report No. 550-9-81-101).

Ugay, S. M., Pogotovkina, N. S., Agochkov, A. I., & Kompanez, V. A. (2013). Reduction of automotive noise pollution. *World Applied Sciences Journal*, *24*(8), 1016-1019.

U.S. Environmental Protection Agency. (2021, August). *Clean Air Act Title IV – Noise Pollution*. https://www.epa.gov/clean-air-act-overview/clean-air-act-title-iv-noise-pollution#:~:text=Noise%20pollution%20adversely%20affects%20the,sleep%20disruption%2C%20and%20lost%20productivity

Winner, L. (1986). The Whale and the Reactor. *The University of Chicago Press*, 19-39.

Yang, F., Cao, Y., Wu, M., Albu, F., & Yang, J. (2018). Frequency-domain filtered-x LMS algorithms for active noise control: A review and new insights. *Applied Sciences*, *8*(11). https://doi.org/10.3390/app8112313