An Investigation of Noise Mitigation Strategies and Socioeconomic Status in New York City A thesis submitted by

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Abstract

This thesis addresses the barriers and biases in the implementation of noise mitigation technology in New York City for future policy and planning. A spatial analysis of demographic data, noise pollution data and Sounds of New York City (SONYC) acoustic sensor placement in NYC compare the relationship between socio-economic status and acoustic sensor technology. Sensor placement data and a stakeholder interview highlight the challenges and benefits of deployment as a non-governmental entity in NYC, contextualized by the socio-economic makeup of the city's five boroughs. Findings from these methodologies conclude that sensor deployment by a non-governmental entity is inhibited by political access. This includes but is not limited to funding, technical resources, and departmental cooperation that further exacerbate the issue of equitable sensor placement throughout NYC. Policy recommendations include increasing the transparency of existing NYC government-deployed sensor technology and creating designated channels for researchers to encourage positive, collaborative growth that optimizes and advances the utility of existing policy.

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Chapter 1: Introduction

Noise pollution is an increasing threat to cities around the world. Researched-based strategies continue to shape and refine municipal approaches to noise mitigation and resilience to accommodate for a growing global population. Technology offers a current, adaptable approach to noise mitigation that competes with dated systems of measure and federal guidelines. In New York City (NYC), noise mitigation strategies in the realm of technology have been met with ambivalence, with operatives on all sides weighing in on the benefits and the dangers to piloting acoustic sensor technology. Global noise mitigation strategies, public health concerns, and socio-economic vulnerability provide context to my analysis on the equitable distribution of acoustic sensor technology deployed in NYC. Noise mitigation tactics employed by NYC curate a response to rising noise complaints using technology, solicited public feedback, and strategic planning. 3-1-1 data and more recently, acoustic sensor technology are relatively recent additions to the sound mitigation landscape straining the utility of existing policy.

The duration and accessibility of Sounds of New York City (SONYC) data, a noise mitigating, acoustic sensor technology deployed by researchers at New York University (NYU), are further mapped and scrutinized as the most publicly accessible of acoustic sensor technology in NYC. I conducted a spatial analysis of sensor technology and vulnerable populations to noise in New York City followed by a policy analysis comparing the compatibility of existing noise policies and new noise mitigation technologies. Discrepancies are found amongst self-reported data, socio-economic vulnerability, and sensor placement. The study concludes with policy implications and areas for future research.

Research questions:

1. How does NYC measure and respond to noise pollution?
2. What is the spatial relationship between noise pollution and socio-economic status in NYC?
3. What is the spatial relationship between acoustic sensor locations and socio-economic status in NYC?
4. What are the barriers to acoustic sensor implementation?

Chapter 2: Background

Noise is defined as “unwanted sound” and noise pollution is defined as continuous or regular exposure to “elevated sound levels” which correlates to noise 70db or above (EPA, 1974; WHO, 1980; EPA, 1981; EPA, 2013; EPC, 2023; CDC, 2022). Short term affects can include interference with work-from-home jobs and concentration, while long-term exposure can lead to cardiovascular disorders, sleep deprivation, anxiety and even premature death (EEA, 2020; Noise Free America, 2010; Re, 2022). Exposure length and decibel level are two major contributors that impact long-term and short-term physical and mental health (Park & Kim, 2015; Wagner, 2018). Ideal noise levels are of decibel levels above 55db(a) outdoors and 45db indoors, that “permit spoken conversation and other activities such as sleeping, working and recreation” were put in place at a time where there was a smaller population of both people and vehicles (EPA, 1974; Smith, Claflin, & Kuskie, 2015).

NYC’s population has grown from 7.94 million to 8.34 million likely outgrowing previously established standards for noise (U.S. Census Bureau, n.d.). Studies by the EPA were done primarily in suburban areas in 1978 and the noise code hasn’t been updated since 2005 (New York City, 2005). These codes and the policies they inform are outdated and likely do not provide an accurate baseline by which to measure and respond to noise in NYC.

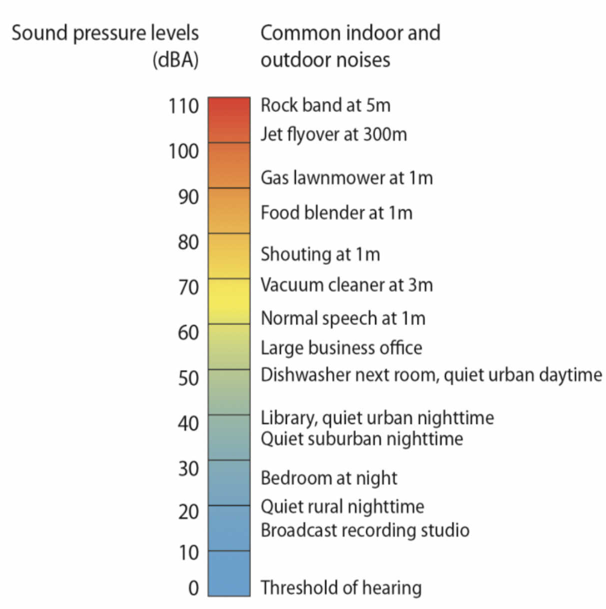

Figure 1: Sound Level Comparisons

Primary noise contributors

Although top noise contributors vary by city, even neighborhood, there are a few noise offenders that are consistent across the globe: vehicular traffic, construction, and seasonal trends. Figure 1 shows a scale of common outdoor and indoor noises, ranked by how loud they are, measured in decibels. This provides a baseline understanding of noise in a day-to-day context.

<u>Vehicular Traffic</u>

Road, rail, and air traffic are global contributors to noise increase around the world (CORDIS, 2016; Canada, 2018; Park & Kim, 2015). Traffic, specifically large trucks, are one of the leading noise contributors in NYC (NYC DOT, 2016). In Figure 2, truck routes pass through each NYC county; truck routes near more affluent areas, like Manhattan, go around the perimeter of the borough whereas in the Bronx, there are 3-4 through-routes contributing to overall vehicular noise.

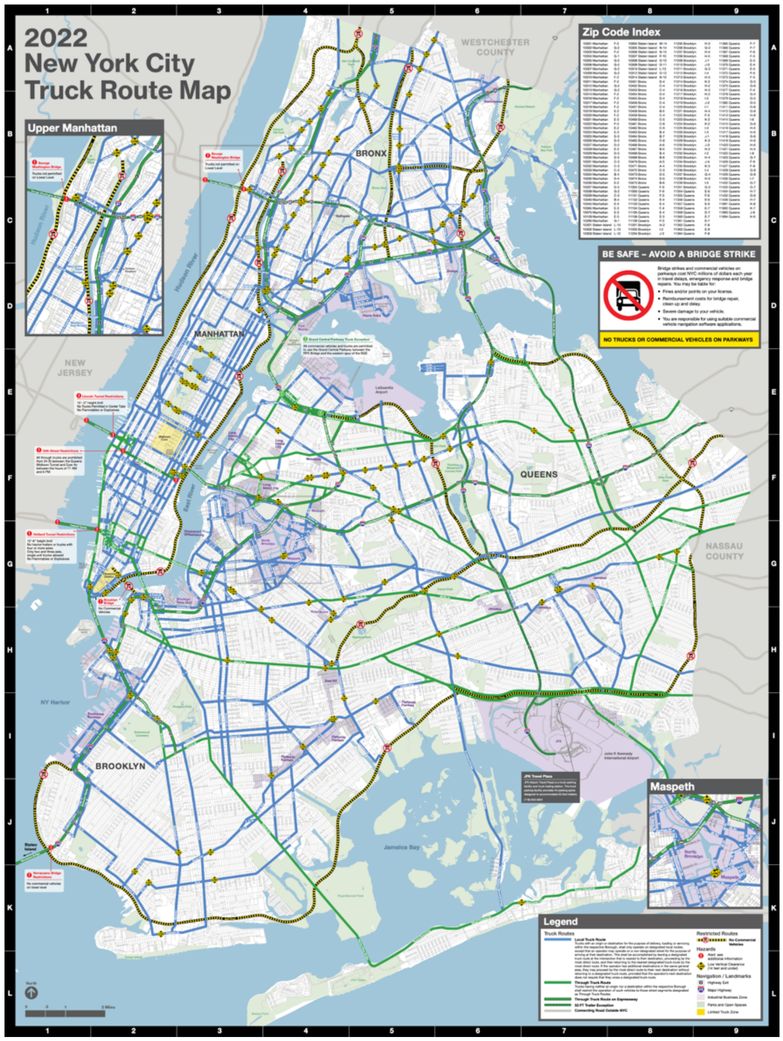

Figure 2: NYC Truck Routes 2022

<u>Construction</u>

NYC active construction maps available through NYC Open Data reveal that there are 2,313 active projects happening in Bronx County and New York County than any other county (NYC Open Data, 2023). A closer look at Figure 3 shows a wide distribution of work throughout the borough, only including part of Manhattan.

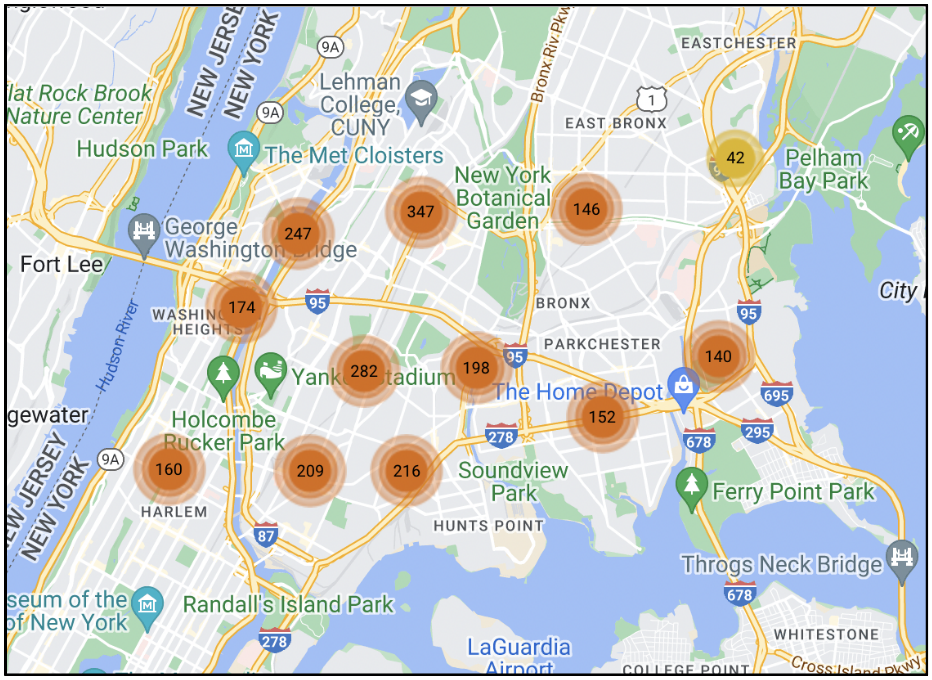

Figure 3: NYC Active Construction

High-traffic, inner-city housing has the highest risk to the effects of long-term exposure to noise pollution due to concentrated amounts of construction, and traffic, whereas “quiet suburban neighborhoods experience ambient noise levels of approximately 45-50 dB (EPA, 1974).”

<u>Season</u>

Pets, HVAC, and parties are some of the highest volume, recurring noise complaints in NYC. Noise pollution is subject to fluctuations based on season, time of day and population density (Munir, Khan, Nazneen, & Ahmad, 2021). On a local level, construction, HVAC, vehicles, parities can create pockets of increased noise in certain areas (Park & Kim, 2015).

<u>How cities measure and address noise</u>

Cities across the world have variable degrees of population, seasonal tourism, noise mitigation strategies and priorities. The most active part of the world for noise research and development is the European Union. Global noise mitigation efforts attempt to identify and standardize urban acoustics for the betterment of residents. The most common approach is to reinforce existing policy through vigilant law enforcement and financial consequences (MOE Japan, 2012; New York State, 2021). In 2009, The European Cooperation in Science & Technology organized Designs for Noise Reducing Materials and Structures aiming to build a collaborative, research-based foundation for soundscape research (COST, 2013). Funded by the European Cooperation in Science and Technology (COST), this set a precedent and direction for future noise mitigation strategies. Members of the European Union (EU) are required to use a standardized method for "noise mapping" as of 2019 (EEA, 2020). Japan's Framework of Vehicle Noise Regulation shares similar approaches with US in that in response to growing noise pollution caused by vehicular traffic, going so far as to ban especially loud mufflers (MOE Japan, 2012; New York State, 2021). As of 2021, Australia has updated their Vehicle Standard to include noise reduction systems and manufacturer accountability (WHSQ, 2021).

Noise abatement strategist like Qcity and The Noise Abatement Society employ an interdisciplinary approach to noise mitigation, incorporating engineers, acousticians, and urban practitioners to develop and inform regional strategy. The Environmental Noise Directive endorses inter-country collaboration to inform noise abatement strategies, highlighting the benefits of cross-cultural input. The Noise Abatement Society (NAS) based in the United Kingdom (UK) collaborates with scientists, acousticians, and practitioners to develop methods and technology for noise control (NAS, n.d.). Affiliate groups and participating countries in the

EU pool mitigation strategies that range from structural improvements, noise density modeling, traffic bans, short-term and long-term feasibility assessments, and noise fees in a collective effort to optimize noise mitigation efforts. Multi-modal noise density modeling using survey data, acoustic sensors and Traffic Noise Synthesizers can model a the noise landscape and inform strategic development (QCity, 2008). Feasibility Assessments consider the economic, technical, operational, and schedule components to urban development. Cities use these assessments to gauge the feasibility of short, mid, and long-term sound mitigation developments. Examples of these developments include exterior sound barriers like sound walls and trees; water features, to mask traffic noise; home insulation and updating ventilation systems can provide relief to residents (CEDS, n.d.; QCity, 2008)

Additional structural improvements in rail near residential areas are the most frequently cited areas for improvement by engineers and developers, due to their prominence in everyday, urban life. The European Cooperation in Science & Technology has organized Designs for Noise Reducing Materials and Structures (DENORMS), to design “multifunctional, light and compact noise reducing treatments” for community noise reduction (COST, 2020). Track modifications in Athens, Greece address the materials and curvature of rail tracks aim to lessen “wheel squeal” of trams, and reduce low-frequency noise, and “quieter surface transport” attempt to reduce sound caused by cars and trains (CORDIS, 2008). Japan echoes this concern when it comes to “tire rolling”, or noise due to tire friction, proposing tires with modified tread and a Tire Noise Labelling system for manufacturer accountability and tracking (MOE Japan, 2012). Although existing conditions inform areas for improvement, it may not take into consideration the broader implications of rail placement based on geographic location. Many cities provide noise-buffering interior design advice to mitigate sound disturbances in residential areas, especially high-density areas (Park & Kim, 2015; New York City, 2005).

Noise fees are another way cities attempt to control noise, and these fees are enforced by local policy vary in effect depending on the cost of the tax. Figure 4 illustrates the drop in decibel levels after employing a 0.5€ fee, and 1€ fee, where the higher fee was more effective in lowering decibel levels. Higher noise fees typically yield a reduction in noise caused by traffic; lower noise fees caused increased noise levels in surrounding areas (QCity, 2008). However, it is possible for this system to be abused without proper checks and balances (Calder, 2023). Congestion pricing in NYC uses tolling around a designated Congestion Relief Zone with scaled pricing to mitigate traffic in and out of the city (MTA, 2024). Traffic bans alleviate noise pollution caused by trucks and vehicle congestion and facilitates low-noise mode-shifts from cars to walking and biking (QCity, 2008). Limiting truck traffic at night, for example, can improve the quality of rest of residents in visitors, elevating physical and mental health (MTonroad, 2023).

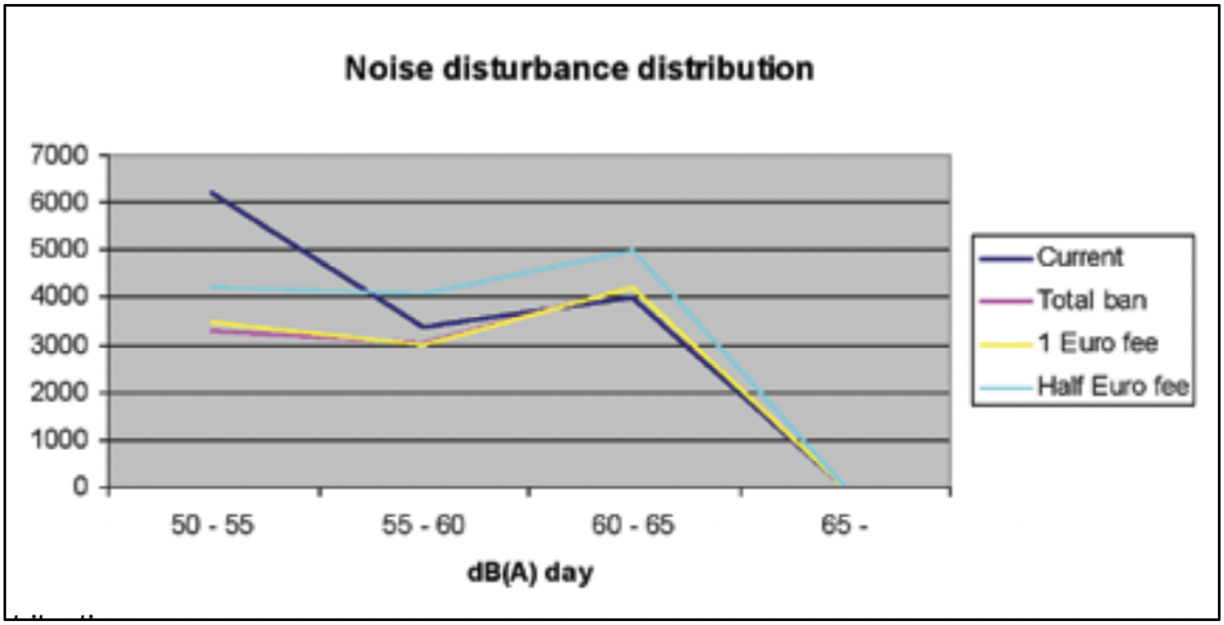

Figure 4: Correlation of Noise Fee and Decibel Level. Source: QCity

Sensor Technology

What does sensor technology offer?

Intelligent sensor technology offers a complimentary, quantitative insight to urban patterns and behavior through an integration of computer science, engineering, and urban planning. Scalable solutions of this technology are based on predictive modelling, ethical data collection, community involvement, and ongoing refinement that strive to reduce transit-related fatalities, noise disturbances, and emissions among other goals. Some sensor technology, like devices deployed by Sounds of New York City (SONYC), only capture audio data whereas others, like Numina, SoundVue and Vivacity incorporate a visual component to their data collection process (Demopoulos, 2023; Numina, 2024; SoundVue, 2024; Vivacity, 2024). Each of these technologies use algorithms and AI to create activity models to measure and predict mobility behavior (SoundVue, 2024; Numina, 2024).

What specifically does sensor technology capture?

Quantitative measurement made available by sensor technology can record urban visuals and audio, sending alerts when triggered by high-decibel inputs for safety optimization for urban residents and visitors alike. Although sensor technology is transit-oriented, it has a wide applicability for research and development from social science, data ethics, and urban innovation. Sensor technology can capture audio and visual data depending on the focus and goals of the organization developing it. The lifecycle of the data captured by sensor technology, namely how the data is captured, processed, distributed, and managed adds depth to the data and its applications.

What are the barriers to implementation, or integration?

Technical challenges include the limited functionality of current software, like GIS, that cannot capture the complexities of sound in predictive models such as "noise maps" (Park & Kim, 2015). Noise tracking is further complicated by a lack of noise tracking in mobile noise sites, like construction sites (Park & Kim, 2015; NYC Open Data, 2023). Standardization for sound collection methods and measurement limit sound mitigation efforts (Park & Kim, 2015). Later in this thesis, I will discuss bureaucratic, on-the-ground challenges that limit the implementation of acoustic sensor technology through a stakeholder interview.

<u>Noise in New York City</u>

New York City is ranked one of the most trafficked, dense cities nationally, and globally (U.S. Census Bureau, n.d.). NYC's tall, narrow corridors trap wind and create invisible tunnels that amplify sound (Suter, 1991). Heating, ventilation, and air conditioning and traffic discreetly raise baseline decibel volumes in homes, and in streets. In addition, tourist attractions like Times Square, Central Park, Brookfield Place, and others, are the most prone to seasonal behavioral shifts and street-level activity increases (Munir, Khan, Nazneen, & Ahmad, 2021).

NYC Noise activists in the early 20th century precipitated the NYC noise code, reinforcing noise as a historic issue that continues to pervade the city (Waits, 2022; Montano, 2020). The NYC Noise Code uses decibel standards similar to those outlined by the EPA, to create guidelines for frequent noise offenders, like construction, music from bars and restaurants, motorcyclists, and more (NYC, 2018). NYC enforces a Noise Policy and offers 3-1-1 noise reporting as a noise mitigation strategy to protect city residents. Guidelines provided by the New York City Department of Environmental Protection suggest residential noise-buffering tactics that include drapes, carpet, and acoustic paneling, among other strategies (EPA, 1981; EPA, 2013). New York City provides a comprehensive overview of their noise code, including frequent noise offenses based on 3-1-1 call reporting. 3-1-1 is a public, default measurement of noise pollution for research and development (NYC, 2018).

Stakeholders

State Government

In 2021, NYC Mayor Eric Adams and his fellow mayoral candidates faced scrutiny related to noise resilience developments in the city (Bronzaft, 2021). Growing concerns and coalitions to fight noise in NYC gather concerns about excessive helicopter flights, dirt bikes and other growing noise concerns that feel ineffectively addressed by local government (Shahrigian, 2021).

Bills like the SLEEP Act prohibit muffler modifications and require police vehicles to have decibel readers to enforce decibel limits (New York State Senate, 2021). The New York City Government has an established flow of responsibility, that leaves little room for interference or alternatives when new solutions are brought to the table by non-government stakeholders, like SONYC (NYC, 2023). Responsible Agencies and Departments for addressing noise complaints include: Department of Environmental Protection (DEP), New York City Police Department (NYPD), Economic Development Corporation (EDC), NYC Department of Sanitation (DSNY), and occasionally, the NYC Office of Technology and Innovation (NYC OTI, 2022; DiNapoli, 2018). Different kinds of noise complaints fall under different departmental jurisdiction; for example, a noise report pertaining to a garbage truck is assigned to DSNY. The NYC Commissioner is responsible for maintaining the NYC Noise Code, which details prevention and mitigation strategies for residents and civil workers. The senate is responsible for reviewing and enacting noise-related policy informed by the work of the Commissioner, and other branches of NYC government (New York State Senate, 2021).

Community partners

Community stakeholders bridge public voices; colleges and community activist groups in NYC often work together to advance noise-mitigation goals in the city. Local colleges and long-standing community activist help shape decision makers response and commitment to reducing noise in NYC. New York University (NYU)-born research group Sounds of New York City (SONYC) partnered with CSAAH and created “sound walks” among other modes of public participation in NYC Chinatown (AANHPI, 2020). Sound walks by Sounds of Chinatown use sensor technology to track decible levels in NYC’s Chinatown, while posing reflective questions to digital supporters blending qualitative and quantitative methods (Sounds of Chinatown, 2021). Activist groups like GrowNYC act as a “middle man” providing resources and direction for those who want to do more for themselves or in their community to mitigate noise (GrowNYC, 2024). For example, GrowNYC has a distilled list of resources for submitting noise complaints, and information on the law that empower citizens to advocate for themselves and their community.

Technology & Data Collection

Data-driven city planning has evolved in stride with technological development over the last 50 years (Angelidou, 2015). Technologies like cellphones, satellites, sensors, and websites capture data where user behavior can inform urban development. The emerging field of data science collects, stores, and interprets these large volumes of data (Lopes & Handforth, 2020). Smart Cities hinge on Big Data to optimize existing systems through evaluating trends in data (Chowdhury, 2021). Researchers can use sound data to identify links between urban sounds and human well-being, where prolonged exposure to high decibel levels can lead to chronic stress, anxiety, and other disorders (Axelsson, Nilsson, & Berglund, 2010; Lee, Mendez, Murakami, Roginska, & Genovese, 2019; Cartwright, et al., 2020; Bello, et al., 2019). The creation of the OTI in January of 2022 (previously the Department of Information Technology and Telecommunications) may signify NYC’s attention to the growing need for data security and transparency. The department liaises between government agencies and departments within NYC for their telecommunications needs, per Title 67 (American Legal Publishing, 2015). Although the creation of this department is promising, it is limited in its application beyond what is outlined in Title 67. This means that technology is only what is considered within the realm of telecommunication, like the installation and maintenance of cable services and electricity. It does not include sensor technology or any other technology that may be in use but is not under the umbrella of Title 67.

Self-reported data

In especially dense cities like New York City, local law enforces decibel limits and quiet hours from 11pm to 7am to regulate sound disturbances (New York State Senate, 2021; New York State, 2021; New York City, 2005). In 2003, NYC deployed 3-1-1, a non-emergency hotline that connects callers to city services while alleviating 9-1-1 emergency call volume (NYC, 2023). Dialing 3-1-1 connects NYC residents and visitors with civic information and city noise disturbance reporting, as well as services to report broken streetlamps, and graffiti to be resolved by local law enforcement (Offenhuber, 2013). 3-1-1 calls for noise disturbances collect identifying information of the report such as the location, noise type, and the agency responsible for resolving the issue. Using this standard of measure, noise data are static events with an associated time, place, and event description. The aggregation of this data suggests the noise density and distribution throughout NYC.

NYC uses call and response times to measure the efficiency of the city's service, aiming to respond to callers in 30 seconds or less. From the time a report is made, the NYC NYPD response time to noise complaints are addressed within 8 hours (NYC311, 2024). Calls and online inquiries are typically resolved by the responsible agency within 24-48 hours (NYC311, 2024; New York City, 2005). The agencies responsible for addressing noise complaints include New York Police Department (NYPD), the Economic Development Center (EDC), the

Department of Environmental Protection (DEP), the Department of Sanitation (DSNY), and the Office of Technology and Innovation (IOT) previously the Department of Information Technology and Telecommunications (DoITT). Each complaint is forwarded to the appropriate jurisdiction and processed accordingly. Open-access data like 3-1-1 call data coupled with advanced technology provide a renewed opportunity for urban governments to build equitable and sustainable cities on foundation of transparency and accountability (Kitchin, 2013).

Acoustic sensors

Contributions to open-access data facilitate research in understudied areas, like the impact of sound in cities. Acoustic sensor technology can be used to inform mitigation strategies for noise pollution (Bello, et al., 2019). Some urban sound studies have explored noise disparity by surveying urban residents and employing the use of sensor technology to evaluate resident experience (García & Faus, 1991; Breton, Daniel J; Haedrich, Caitlin E; Kamrath, Matthew J; Wilson, Keith D;, 2019; Wang & Norbäck, 2021; Bello, et al., 2019).

SONYC

Acoustic sensor technology developed and piloted by Sounds of New York City (SONYC) offers unique insight into the social sound injustices in New York City's most densely populated corridors. SONYC was conceived when New York University researchers identified a deficit in existing technologies to parse competing noise sources in the urban environment and sought to develop a solution (Bello et al., 2022). The team was awarded a grant of over 4.5M dollars by the National Science Foundation (NSF) in 2016 to develop a cyber-physical system "for the monitoring, analysis and mitigation of urban noise pollution (NSF, 2022; Bello, et al., 2019)." SONYC sensor technology adds dimension to urban soundscapes capturing "foreground" and “background” determined by the perceived proximity of an object. Sensor hardware is cost-effective, at a cost of approximately $80 per unit (Bello, et al., 2019).

Figure 5: SONYC sensor (Bello et al., 2022)

SONYC’s approach not only provides continuous data collection but adds context and dimension to sound reporting. Additional information such as precipitating sound events, automating sound data filtration using artificial intelligence advances technological development for sensitive data collection. With 56 sensors deployed across three NYC boroughs: Manhattan, Brooklyn, and Queens, SONYC’s sensors operate continuously offering a greater range of environmental context and dimension for 3-1-1 reports. Sounds that reach a reportable decibel threshold based on New York City’s noise code could provide a way to identify violators. Figure 6 is a sample analysis of a study done by SONYC, where they compared noise complaints filed by 3-1-1 callers and acoustic sensor data in Washington Square Park, NYC.

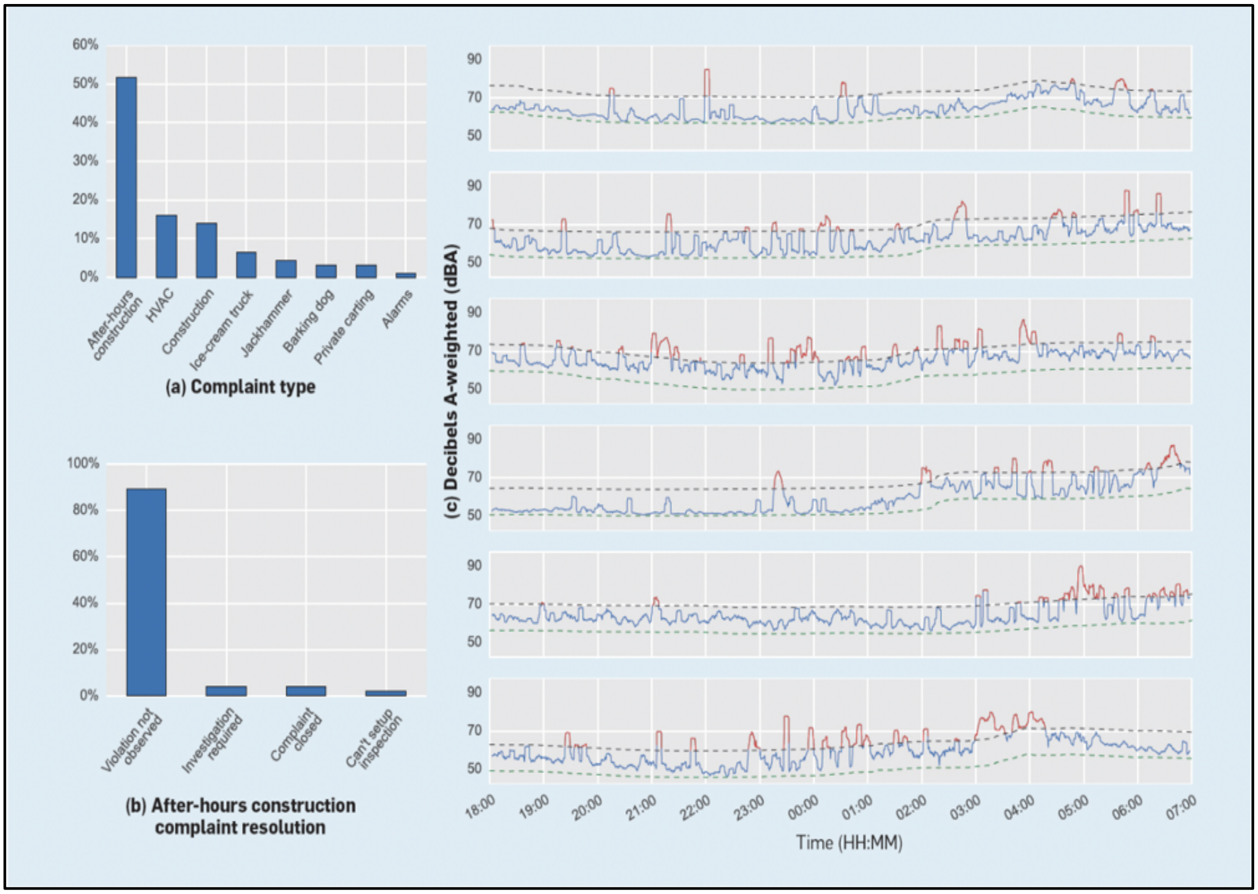

Figure 6: 3-1-1 Reports and Decibel Levels Correlation

In Figure 6, reportable noise offenses that exceed 70 dB are shown in red. Based on the data, there are approximately 85 reportable noise offenses in a 12-hour period in Washington Square Park at the time of this study. Presently, 56 SONYC sensors are currently distributed across three NYC boroughs: Manhattan, Brooklyn, and Queens. At an average production price of 80 USD, SONYC sensors provide a cost-effective, in-depth noise monitoring solution (Nordby, 2019; Cartwright, et al., 2020). This project has been funded by the National Science Foundation for six years, with the last grant renewed in 2022 (NSF, 2022).

ShotSpotter

However, SONYC is not the only or the first organization to employ the use of acoustic sensors to capture valuable sound information. Acoustic sensors have been used by law enforcement in NYC since 2015 to mitigate public shootings (Schlossberg, 2015). ShotSpotter uses acoustic sensors to detect gunfire by triangulating location and keeps record of frequency (SoundThinking, n.d.). ShotSpotter aims to help reduce crime in NYC (SoundThinking, n.d.). The claimed public health technology has met fierce speculation as ShotSpotter is a purportedly racist technology that elicits criticism from activist groups (Amnesty International, 2021; Stanley, 2021). Additionally, prioritization of sensor technologies seems to be given to NYPD (NYPD, 2024). Although this prioritization and selective access mitigate shootings, but without broader application and development neglects other noise sources that cause long-term physiological harm. Unlike SONYC, ShotSpotter does not give public access to the coordinates of their sensor technology.

Challenges

Sensor technology comes with a range of challenges, some of which can be classified by the following:

Technological

- <u>Hardware longevity</u>
    - Sensor life span is short (Mydlarz, et al., 2019).
- <u>Protecting, processing and storing sensitive information</u>
    - Cloud storage would be necessary to accommodate for the volume of data collected via acoustic sensors; where 311 data is publicly available for

researchers, citizens, and others, acoustic sensor data would be stored in a cloud and may have restricted use (Nordby, 2019).

- Additionally, classifications of noise could vary necessitating an “industry standard” for sound classification (Nordby, 2019).
- There have been some attempts at reducing the “noise” in conscientious sensor data to do on-device classifications (Nordby, 2019).
- Privacy concerns for Big Data and cloud storage (Nordby, 2019).
- Need to find a way to eliminate/parse “Noise” in data (Nordby, 2019).

- <u>Cost</u>
    - Sensors need to be in-expensive (Nordby, 2019).

Political

- <u>Interference of existing government initiatives and neighborhood characteristics</u>
    - Criticisms of this data collection method as partially skewed due to highly influential factors of the data such as neighborhood characteristics, and targeted government initiatives in some neighborhoods (Mulligan, Cuevas, Grimsley, Chauhan, & Bond, 2019).
- <u>Unfair distribution/use of existing sensor technologies</u>
    - Ethical concerns (Nordby, 2019; Amnesty International, 2021).
    - Need dense sensor placement to be equitable and effective (Nordby, 2019).
    - SoundVue has made headlines as a purportedly invasive technology, further demonized by being stationed in “rich” neighborhoods, like Manhattan (Demopoulos, 2023).

Socio-Economic Indicators of Noise Vulnerability

There are many factors that can contribute to urban noise vulnerability such as population density, crime, and poverty. Particularly, there are strong links between socio-economic status and sound disparity (ATSDR CDC, 2022). The vulnerability index provided by the Economic Development Corporation (EDC) scores socio-economic vulnerability factors on a scale of 0 (lowest vulnerability) to 1 (highest vulnerability) in New York City as the following: Bronx (0.9793), Brooklyn (0.8549), Queens (0.7855), Manhattan (0.5554), and Staten Island (0.3975) (ATSDR CDC, 2022). As population grows, more communities are at risk of the negative impacts of noise pollution (Stewart, Russell, & Luz, 1999). Over the years, NYC has seen an increase in noise complaints that have risen in parallel with the growing population (DiNapoli, 2018). Construction is among the most reported noise offense, which could also be related to the need for new infrastructure and maintenance to accommodate a growing population.

Violent crime rates are one product of noise pollution in NYC, where decibel data shows that as noise levels increase, so does violent crime (Hener, 2022). The 75th precinct in Brooklyn continues to make history as one of the bloodiest precincts in the city (Celona, Vago, & Golding, 2022; NYPD, 2024; NYC OpenData, 2024). In 2023, the most shootings in NYC took place in Brooklyn, and the Bronx (Roberts, Moore, & Fitz-Gibbon, 2023). In 2019 alone, there were more than twice as many violent crimes in NYC than in the rest of New York State (New York State Division of Criminal Justice Services, 2020). Finally, poverty rates are a driver of violent crime where age, race, employment status, and educational attainment variables play a role

(Quednau, 2021). Recovery from public health crises like the COVID-19 pandemic exasperate poverty rates, further straining relationship between poverty and violent crime (CPSP, 2021).

There is a wealth of information related to noise and public health and noise prevention technologies and techniques. However, few United States studies blend qualitative and quantitative studies of noise while offering policy solutions that consider the changes in population, seasonal tourism and vehicular traffic that influence the sound landscape. The gaps unaddressed by the literature lack comparative studies of acoustic sensor technology and 3-1-1 noise reporting to evaluate noise disparity. Where NYC is a hub for activity and innovation, this thesis responds to this question using SONYC as a case study, guided by the research questions. Furthermore, the Discussion chapter of this thesis will offer suggestions for updated policies and practices to enhance noise accountability in NYC.

Chapter 3: Methods

With an understanding of existing and developing noise mitigation strategies, I will use open-source data from SONYC and US Census data to evaluate the relationship between noise and socio-economic status using SONYC's acoustic sensor locations used for noise mitigation in NYC. I will use a combination of spatial analysis and stakeholder insight to create a comprehensive presentation of these data sources and relevant policy to explore research questions 2 & 3:

- What is the relationship between noise pollution and socio-economic status?
- What are the geographic disparities between acoustic sensor locations and socio-economic status in NYC?

To contextualize the sensor locations in NYC, I will provide demographic data indicative of socio-economic vulnerability using three indicators: 1) population density, 2) violent crime, and 3) poverty, represented by median household income. SONYC offers coordinate-level data for 56 sensor locations deployed in 2019, which I will use in plot in conjunction with 3-1-1 call data to produce individual and aggregated maps of SONYC sensor locations, socio-economic and 3-1-1 call distribution across NYC.

Spatial Analysis

First, I wanted to visualize socio-economic indicators by U.S. Census tract to simplify the data into visual patterns, where clusters and sparse distributions of data could quickly identify more or less vulnerable neighborhoods, boroughs and tracts. This contextualizes NYC broadly, before adding noise data and extracting most and least noise-afflicted tracts in their socio-economic contexts.

Using 2021 American Community Survey (ACS) 5-year estimate data, I used Social Explorer to generate three maps of each of my chosen socio-economic indicators, for the year 2021:

- Population Density
  - Measured as persons per square mile, by tract.
- Violent Crime
  - Measured as the number of violent crimes by tract. According to the FBI's Uniform Crime Reporting (UCR) Program, violent crimes fall into one of four categories: murder and nonnegligent manslaughter, rape, robbery, and aggravated assault (FBI, 2024).
- Median household income
  - Measured as the median annual income for each household, where household includes the total income of the people living in a home, not just by those who are blood related. This consolidates renters in NYC to one household. Median household income by tract in this study as a measure for poverty.

To narrow my findings for a more detailed comparison after mapping, I extracted the five highest and five lowest values from the noise vulnerability factors by tract and county: crime, income, population density. I removed the tract data to simplify the table, and to simplify the results to county-level for a clearer comparison.

Next, I used Kepler to visualize the noise landscape in NYC using 3-1-1 call data and SONYC sensor locations. Kepler is a user-friendly data visualization software for making maps. 'Noise landscape' in this context refers to areas where there is attention to noise: noise complaints reported and technology that monitors noise. To obtain a full report of 2019 3-1-1 call data, I used the NYC Open Data Portal and then I used Kepler to visualize the data on a map. I then overlayed SONYC acoustic sensor locations over the demographic data for comparison.

<u>Data collection description</u>

1. <u>Accessing 3-1-1 data</u>
    1. Access 3-1-1 service requests through NYC Open Data portal
    2. Filter by:
        i. Created Date: 01/01/2019 at 00:00 to 12/31/2020 at 23:59
        ii. Filter columns by 'Complaint Type: Noise'
        iii. Result: 479,052 rows
    3. Export report CSV file
    4. Load CSV into Kepler
2. <u>Accessing SONYC data</u>
    1. Access acoustic sensor point data though Zenodo
    2. Export CSV file
    3. Load CSV into Kepler

<u>Stakeholder Interview</u>

To achieve a better understanding of SONYC's potential challenges to implementation of acoustic sensor technology in NYC, I had a conversation with one of the leading contributing researchers to the project. Although the team had disbanded prior to our conversation, this researcher actively plays a key role in the continuation of SONYC's research through acoustic technology. Over the course of an hour, insights from our conversation addressed the fourth and final research question:

- What are the barriers to acoustic sensor implementation?

I prepared for this virtual meeting by creating a list of questions, which can be found in the appendix of this thesis. This study was submitted to the Institutional Review Board (IRB) for review and was determined that it is not Human Subjects Research, per reference number: STUDY00004583. Framed by the research question, our conversation yielded the problem-and-solution framework for future research.

Chapter 4: Results

In this chapter, the maps and interview data are presented. Although the maps reflect tract-level data, simplifying the general area by county (Richmond, Kings, Queens, Bronx, Manhattan) creates quick visual comparisons, where tables illustrate more granule, tract-level comparisons.

<u>Spatial Analysis</u>

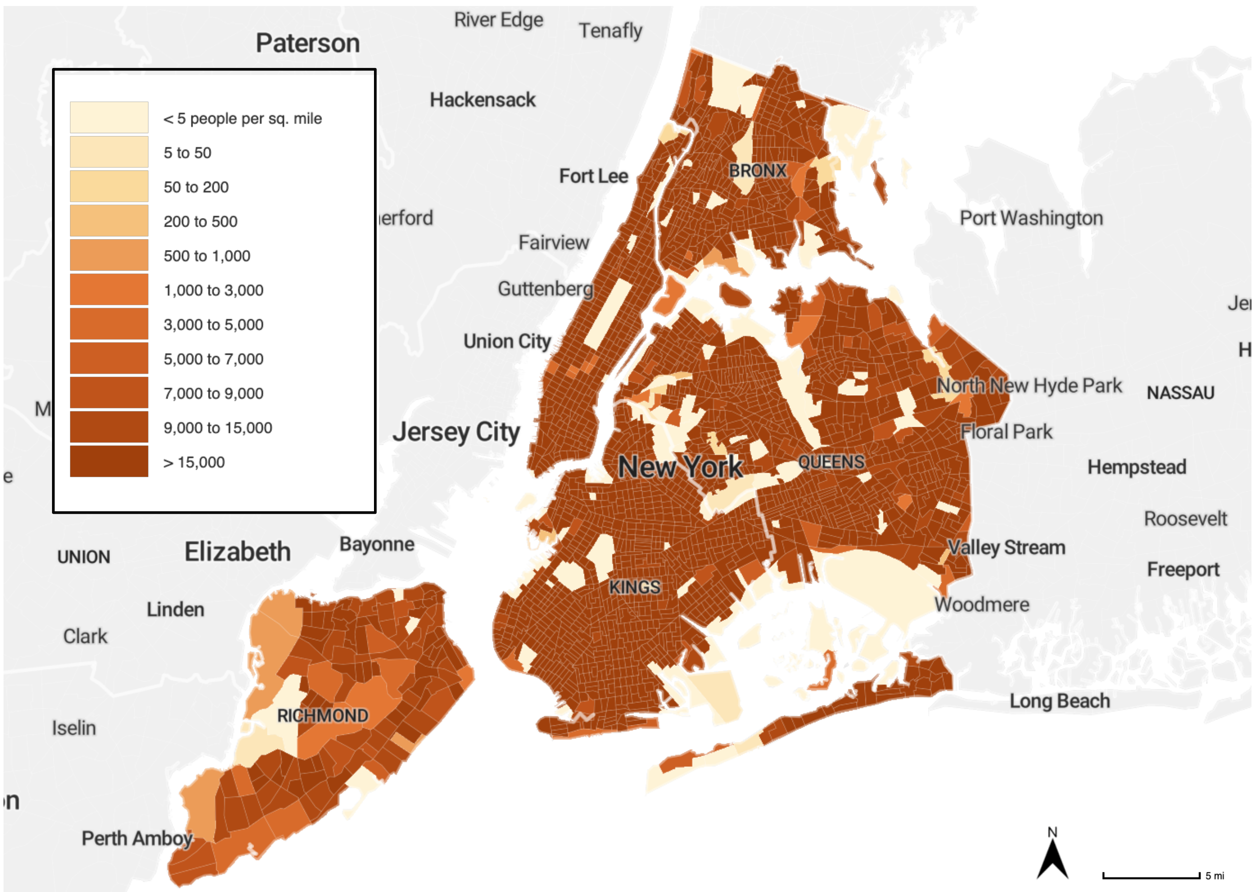

Figure 7: Population Density in New York City, NY 2021 (data source: Social Explorer)

In Figure 7, the population of NYC is least dense in Richmond County (the borough of Staten Island), and tracts zoned for public-use throughout NYC. The other four counties, Manhattan, Kings, Queens, and the Bronx, are nearly equal in density. Because of this distribution, the latter four counties may be more at risk of noise disparity under this socio-economic measure based on population density as a primary contributor to noise.

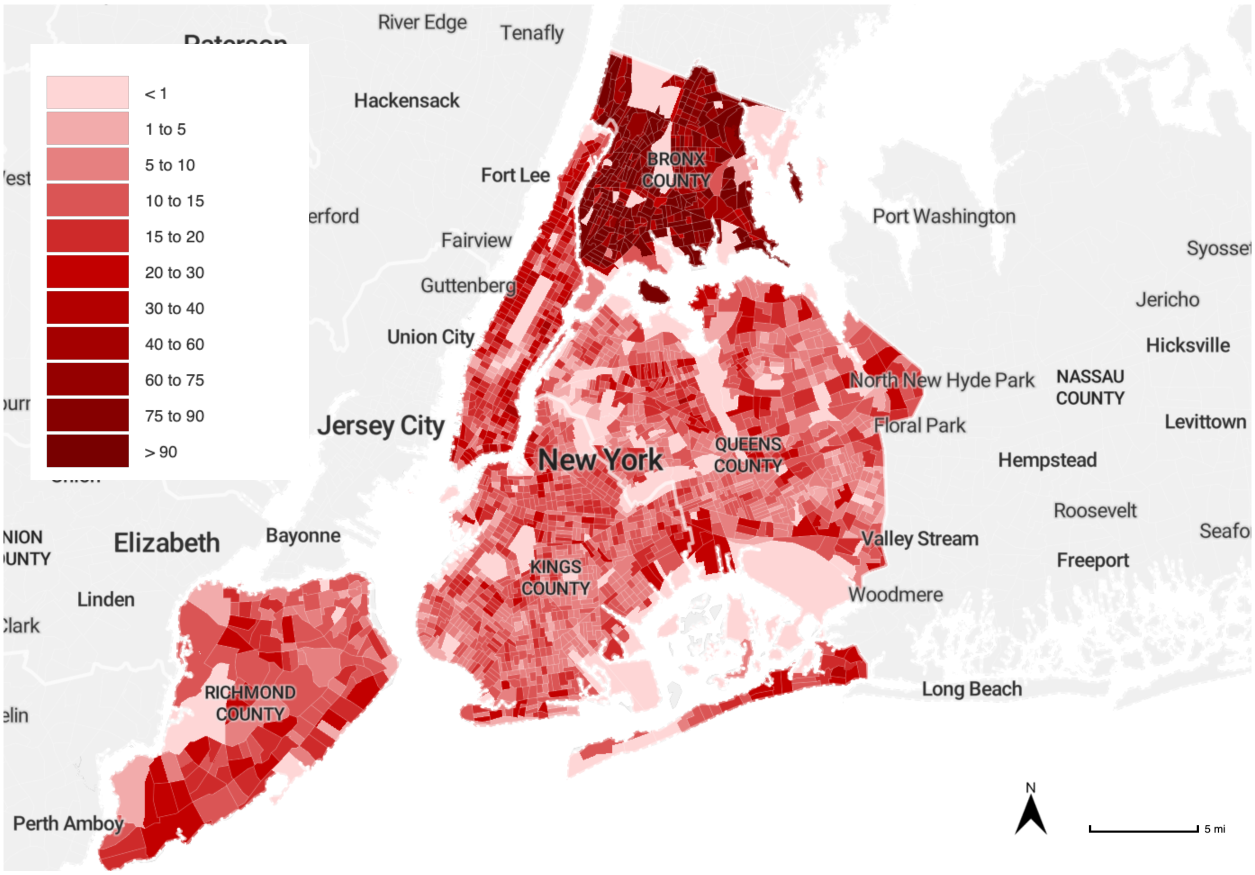

Figure 8: Violent Crime in New York City, NY 2021 (data source: Social Explorer)

In Figure 8, violent crime in NYC occurs most in Bronx County, almost exclusively in residential areas. Using the map as a visual comparison, Manhattan, Richmond, then Queens County have the most violent crimes in order from most to least. Based on this inference, the Bronx is the most at risk of noise disparity under this socio-economic measure based on violent crime being a primary contributor to noise.

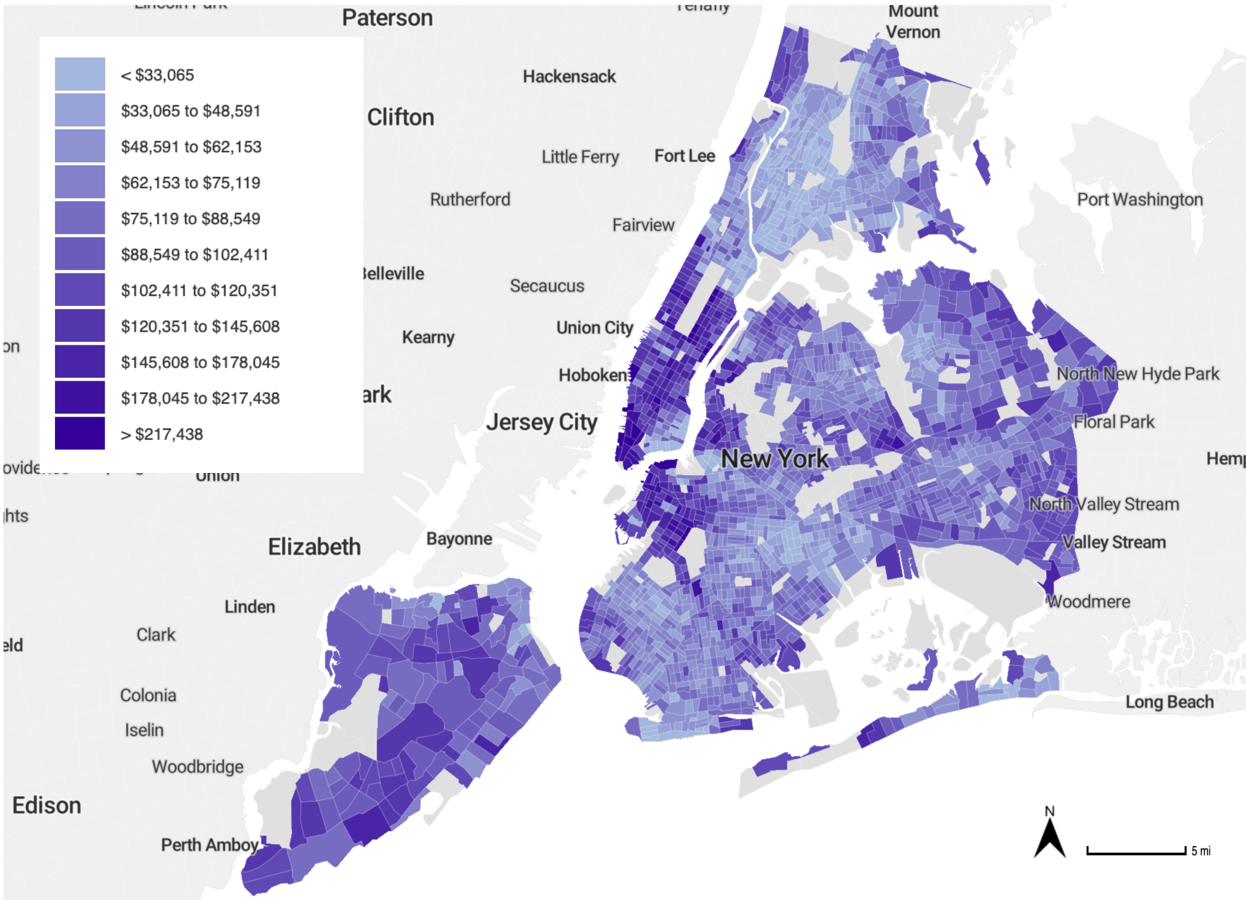

Figure 9: Median Household Income in New York City, NY 2021 (data source: Social Explorer)

To create this map, I used an equal distribution interval, where value of '0 Families' were not considered in the evaluation of most and least affected tracts, however they are represented on the map. In Figure 9, families with an income below poverty level are most concentrated in the Bronx and upper Manhattan. Queens county displays a relatively even distribution of poverty throughout the county, unlike the Bronx and Manhattan which experience more contrast in poverty range by tract. Because of this distribution, the Bronx, followed by upper Manhattan, may be most at risk of noise disparity under this socio-economic measure based on poverty being a primary contributor to noise.

County	Crime	County	Income	County	Population
Bronx	1	Kings	11988	Kings	10.03398
Kings	1	Kings	12073	Bronx	12.66454
New York	1	Richmond	13855	Richmond	14.65394
New York	1	Kings	14446	Queens	18.35453
Queens	1	Kings	14494	Queens	28.95963
Bronx	185	Kings	250001	New York	219123.3
Bronx	187	New York	250001	Bronx	220225
Bronx	187	New York	250001	Queens	241076.2
Bronx	190	New York	250001	New York	260977
Bronx	194	New York	250001	New York	310137.5

Figure 10: Values of Noise Vulnerability Factors by County in New York City, NY 2021 (data source: US Census)

Figure 10 extracts the most and least effected tracts of each mapped category, grounding the visual data with numeric values to deepen the illustration of the discrepancies of income, crime, and population. Where New York County is among the least in crime and the highest in income, the Bronx has the highest crime and Kings has the lowest income. Notably, the most and least effected tract data in this table may look different if the most and least recurring counties in the lower and upper quartiles were averaged. In Figure 9, the Bronx is quickly identifiable as being among the lowest-income county compared to the other counties. This socio-economic data lays the stage for 3-1-1 reports and acoustic sensor placement in NYC.

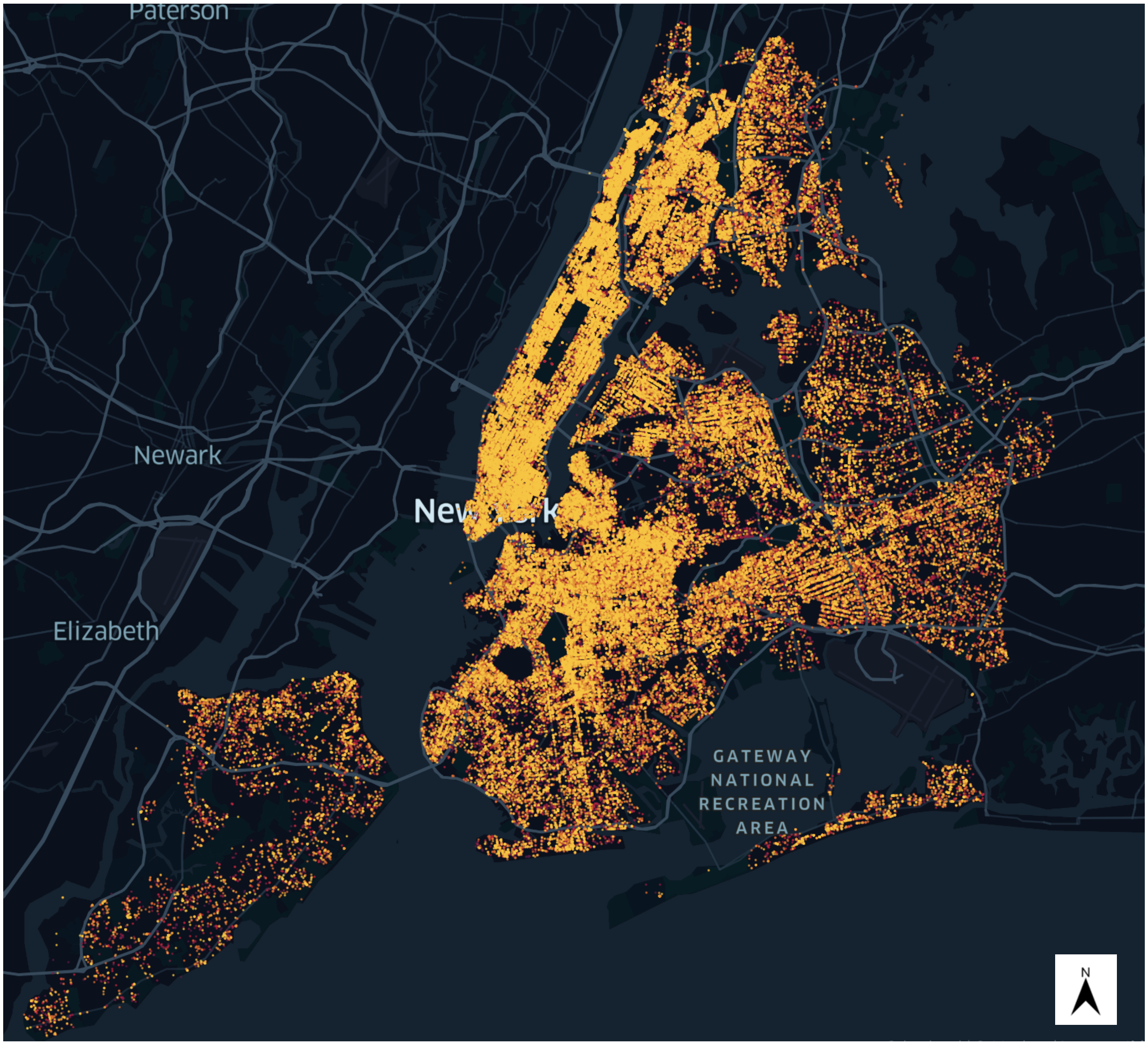

Figure 11: 3-1-1 Noise Complaint Distribution in 2019 (data source: NYC311)

Based on the call distribution presented by the map, the most concentrated noise complaints occur in Manhattan, north Kings County, and west of the Bronx and taper off toward Richmond County, and Queens. There are almost no noise complaints in public green spaces like Central Park, Prospect Park, and the Green-Wood cemetery. Based on this distribution, Manhattan, the Bronx, and Kings are the most at-risk of noise disparity based on 3-1-1 calls being the primary measure of noise in NYC.

Now, how do SONYC sensor locations compare to 3-1-1 call distribution? SONYC acoustic sensor data contains coordinates of 56 sensors deployed in three NYC boroughs: Queens, Brooklyn, and Manhattan. SONYC is a multilabel, multi-class dataset containing 18,515 sound recordings in Wave Audio File (WAV) format that includes metadata on where and when the audio was recorded; all recordings are labeled by Zooniverse volunteers and a verified subset set (1,385 recordings) are annotated by the SONYC team (Cartwright et al., 2020). To date, more than half of SONYC's acoustic sensors are in area codes 10012 and 10003, near New York University and Washington Square Park, and there are clusters of 5 to 6 sensors in Midtown, and Brooklyn Heights. SONYC sensor point locations are available for public download from the SONYC website. After downloading the CSV file, I imported it directly into Kepler.

There are five counties in NYC: New York County (Manhattan), Kings County (Brooklyn), Bronx County (The Bronx), Richmond County (Staten Island), and Queens County (Queens).

Figure 12: SONYC Sensor Locations in 2019 (data source: SONYC)

SONYC sensors occupy only three out of five NYC counties as shown in Figure 12: New York County, Queens County, and Kings County, demographic information and 3-1-1 call density for all five counties add context for vulnerable neighborhoods. To incorporate this into the analysis, I overlayed SONYC sensor locations to compare the distribution of 3-1-1 call density and sensor locations.

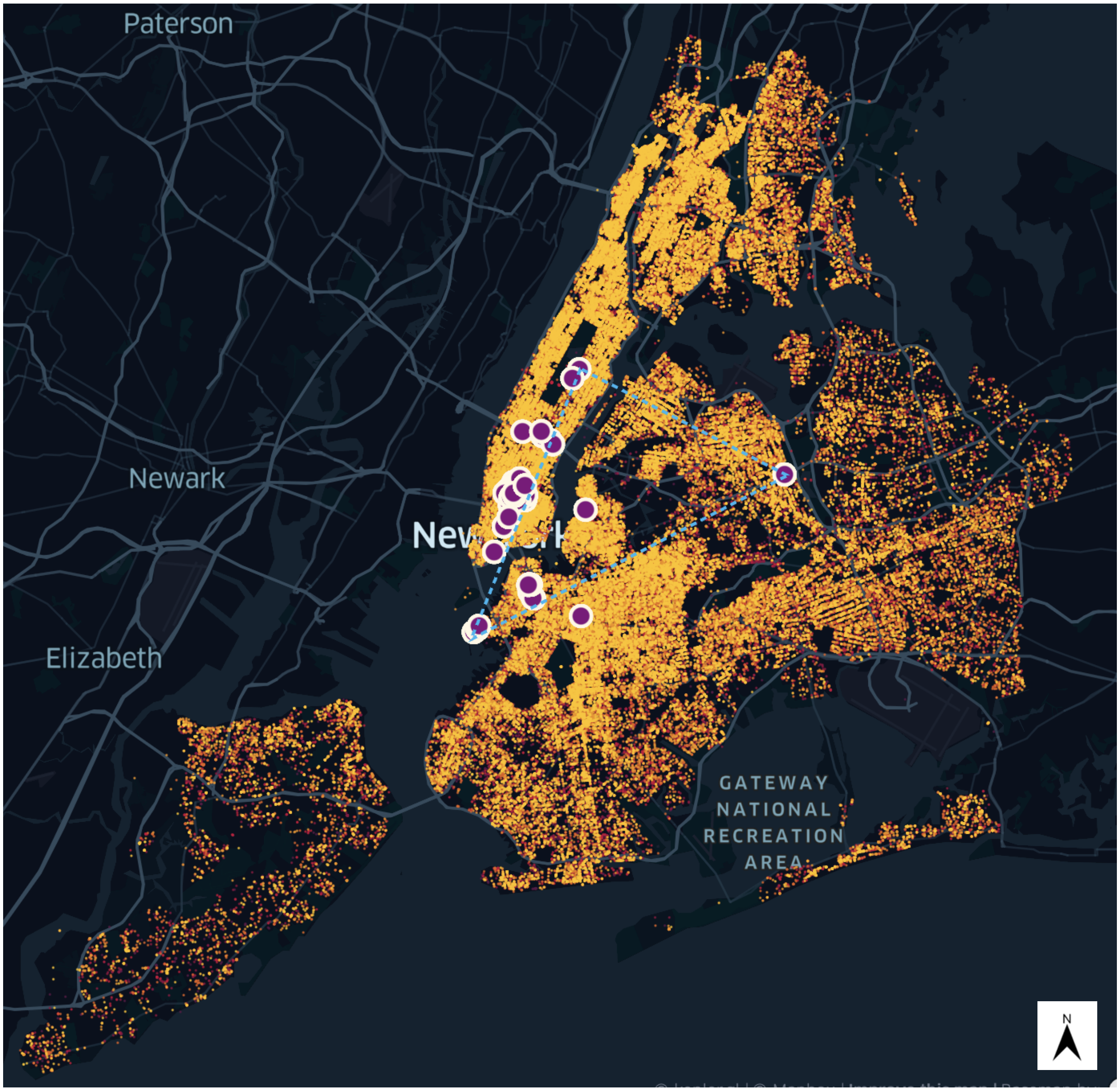

Figure 13: Aggregation of 3-1-1 Call Data and SONYC Sensor Locations 2019 (data sources: NYC311 and SONYC)

Finally, I extracted the five most and least noise-afflicted tracts based on 3-1-1 call data and superimposed them as points on the aggregate noise map, as shown in Figure 13.

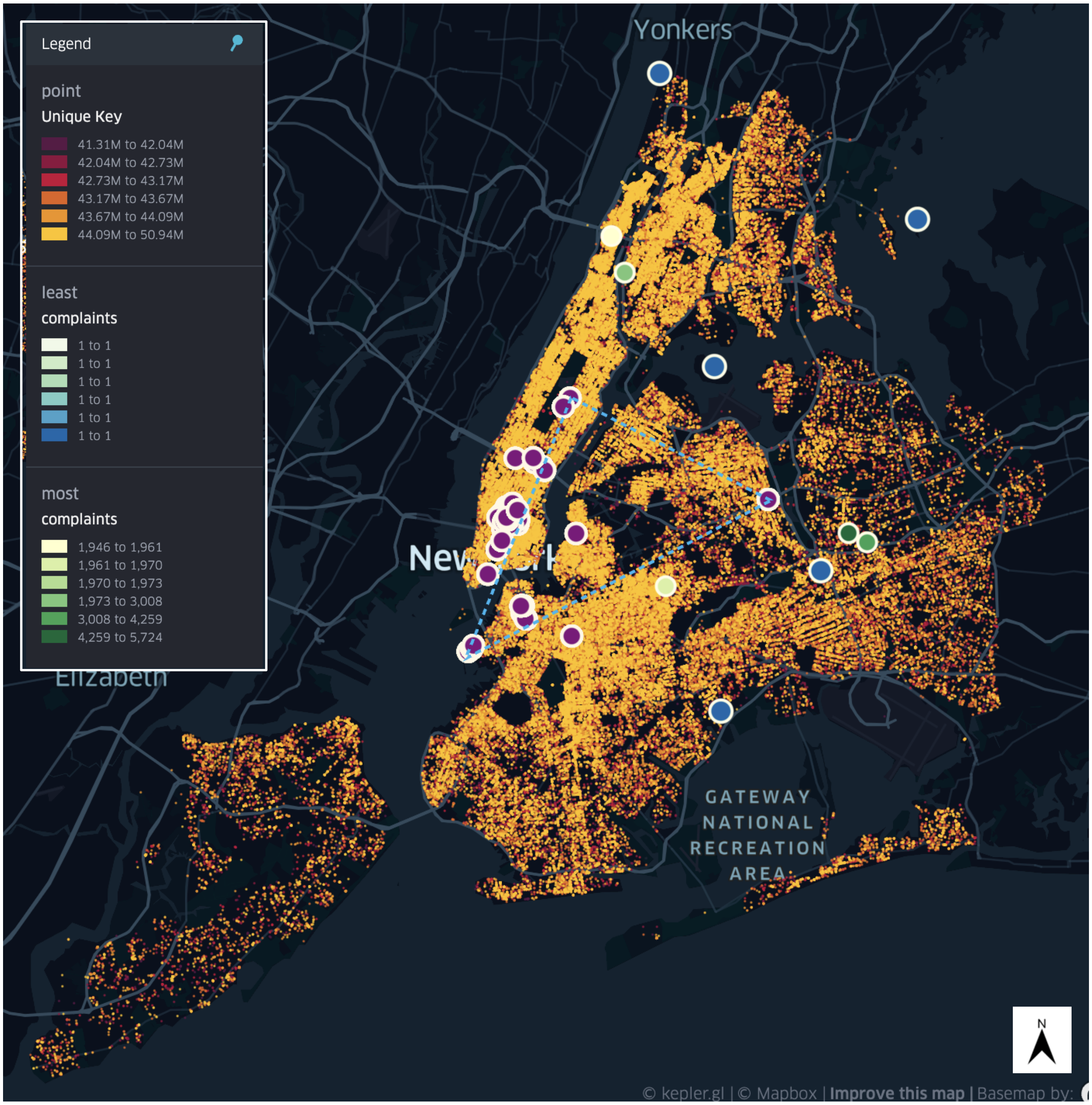

Figure 14: Most (green) and least (blue) tracts effected by noise in 2019 (data source: NYC311 and SONYC)

The aggregate map of 3-1-1 call data, SONYC sensor locations, most and least-afflicted tracts based on 3-1-1 call volume show SONYC sensors clustered in Manhattan and Queens in locations directly related to or affiliated with New York University. Figure 14 shows that the most noise-afflicted tracts (those with the highest 3-1-1 reports) are typically found in the nucleus of a county whereas the least afflicted tracts are found on the outskirts of NYC. Using Census Data and SONYC sensor placement data, I found that:

1. Aggregate maps show most acoustic sensor placement in high-income, relatively safe, dense tracts which may not be the most representative sample of noise disparity.
2. Acoustic sensors are located on or near research NYU campus and affiliated sites.

Violent Crime (least)			Income (least)			Pop. Density* (least)			3-1-1 Calls (least)		
Tract #	*County*	*Count*	*Tract #*	*County*	*Count*	*Tract #*	*County*	*Count*	*Tract #*	*County*	*Count*
276	Bronx	1	808	Kings	11988	702.02	Kings	10.03398	1	Bronx	1
285.01	Kings	1	352	Kings	12073	334	Bronx	12.66454	319	Bronx	1
109	New York	1	40.03	Richmond	13855	228.01	Richmond	14.65394	516.02	Bronx	1
112.02	New York	1	910	Kings	14446	561	Queens	18.35453	1070	Kings	1
1.04	Queens	1	1210	Kings	14494	199.02	Queens	28.95963	216.03	Queens	1
Violent Crime (most)				**Income (most)**		**Pop. Density* (lmost)**			**3-1-1 Calls (most)**		
393	Bronx	185	21	Kings	250001	261	New York	219123.3	263	New York	1946
225	Bronx	187	21	New York	250001	403.02	Bronx	220225	549	Queens	1969
358	Bronx	187	33	New York	250001	455	Queens	241076.2	189	Bronx	1973
413	Bronx	190	99.01	New York	250001	154.03	New York	260977	1267	Queens	3526
386	Bronx	194	114.01	New York	250001	136.02	New York	310137.5	1257	Queens	5724

* Population Density is calculated by dividing the total U.S. population (316 million in 2013) by the total U.S. land area (3.5 million square miles).

Figure 15: Noise Vulnerability Factors by Tract

Grounding the spatial data in tract-level statistics further distinguishes the relationship of socio-economic status and 3-1-1 call reporting, as shown in Figure 15. Samples by tract reveal a possible discrepancy between noise reports and potential sound vulnerability, for example:

1. The Bronx has the most violent crime, and the least amount of 311 calls.
2. New York county has the highest income (4 out of 5 tracts) and one of the most amounts of 311 calls by tract (1 out of 5).
3. Kings has the lowest income by tract (4 out of 5 tracts) and incurs the least amount of 311 calls by tract.
4. The most noise-afflicted county by tract is Queens, but infrequently appears elsewhere on the table.

Stakeholder Interview

Figure 16 summarizes the following sections in extracts of challenges (left) and resolutions (right) from my stakeholder interview about SONYC deployment. These four points emerged as consistent themes throughout our conversation, and provide a quick reference of the following sections.

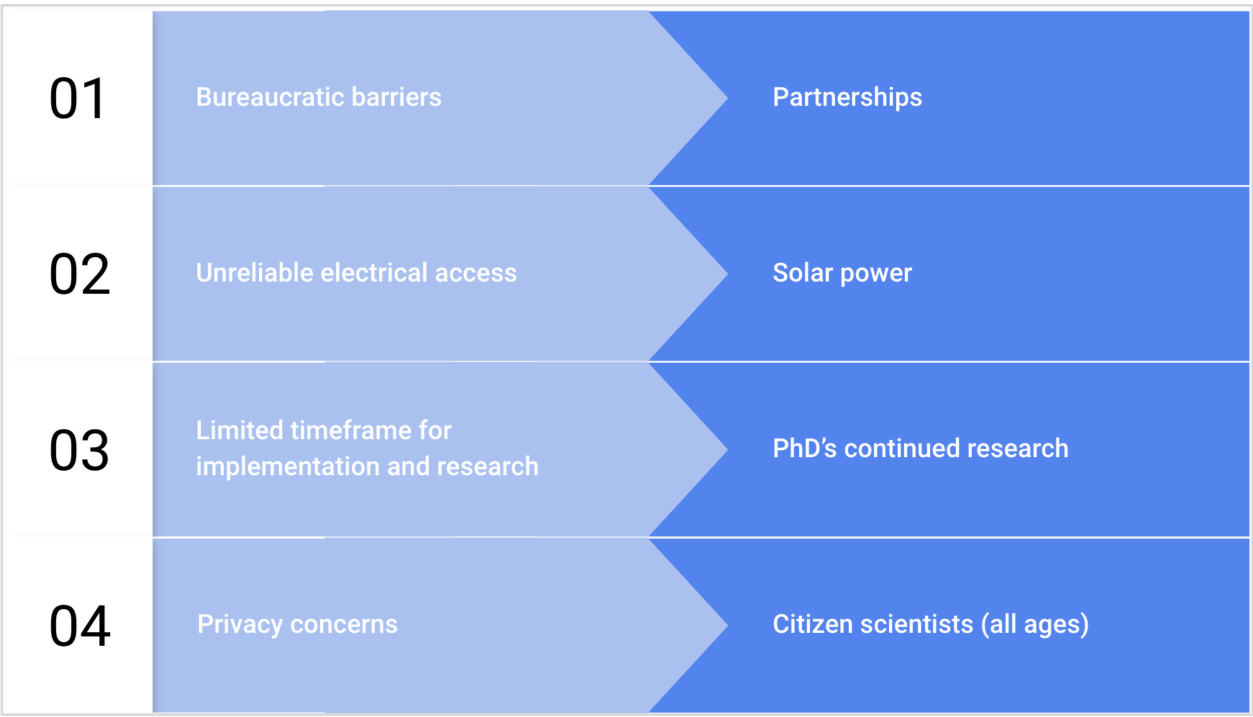

Figure 15: Challenges and Solutions Flow Diagram (SONYC)

Challenge: Bureaucratic barriers

Conflict with existing rules and regulations of the Department of Transportation (DOT) was the leading challenge to implementation in terms of power and network connectivity of acoustic monitoring. In the early stages of implementation, SONYC sought to mount acoustic sensors to light poles, as they offered diverse locations and electrical outlets as a source of constant electrical power, which the sensors required. Although the Department of Environmental Protection (DEP) and the mayor agreed to participate in the project, these combined forces resulted in implementation opportunities near DEP jurisdiction, which did not include residential areas. The interviewee described initial deployments as “opportunistic”, mostly confined to NYU campuses and private faculty residences.

Although no names were disclosed in our discussion, the interviewee noted that partnerships within downtown Brooklyn business revitalization areas and the Department of Environmental Protection (DEP) were ‘proactive, critical partners’ to sensor deployment. The DEP offered locations within their jurisdiction for SONYC sensors to be installed, which offered more opportunity for deployment despite there being limited residential areas for noise tracking. When there was a residential noise complaint routed through the DEP, SONYC could offer to ship the complaint issuer a sensor to address their noise concerns, and advance noise research in a residential area.

Finally, later iterations of SONYC sensors were built with solar panels, a renewable energy source that did not require an electrical output. This transition lessened any dependency on the DOT and enabled some domestic deployment.

Challenge: Public reception

Privacy and equitable deployment were at the forefront of SONYC’s research design to mitigate public suspicion and resistance to continuous sound monitoring technology. SONYC proactively reached out to the media about the nature of their project which enabled them to “get ahead” in addressing public suspicion around the technology and deployment (WBUR, 2019; Barnes, 2017). Researchers for SONYC anticipated concerns about privacy and data security and made a significant effort to communicate how the technology worked, what it was used for, and what was done with the data. This ensured that the project goals and implications could be easily digestible by the public and readily available.

Soliciting the help of “citizen scientists” to code their digital sound library engaged NYC residents in the early stages of data cleaning and processing. This invitation strengthened the relationship between SONYC and the public while cleaning and interpreting large amounts of data that could later be used to teach Machine Learning (ML) algorithms (Cartwright, et al., 2020). K-12 STEM education camps encouraged young New York residents to participate in the research project, ultimately making the entire process accessible and relatable to all citizens. This personalized the SONYC project and built a positive reputation based on transparency and openness (NYU, n.d.).

Challenge: Project funding and timeline

Project funding by the NSF began in July of 2016 and ended in July of 2022 with awards ranging from 1 million to 13 thousand USD (NSF, 2022). Although SONYC’s funding timeline has ended, six years of funding has yielded multiple continuous learning and growth opportunities for various areas of the project.

PhDs spawned because of SONYC research and continue to improve in the areas of Machine Learning and sound research, according to the interviewee. Learning how to work with, process and interpret Big Data are challenges on the horizon of this data collection method, that has been undertaken by PhD students interested in SONYC’s work.

Chapter 5: Discussion and Policy Recommendations

SONYC offer a competitive, cost-effective, self-sustaining technological addition to the noise monitoring landscape that balances biases in existing data collection methods. 3-1-1 on its own is not enough to show a clear picture of noise pollution disparities in NYC. Discrepancies in 311 reporting and acoustic sensor data illustrated in the SONYC case study alludes to broader implications of deficits in 311 data such as call distribution does not align with compelling socio-economic factors to noise in NYC.

Mapping the distribution of sound disparity broadly across NYC reveals geographic disparities between SONYC acoustic sensor locations. Areas like the Bronx and upper Manhattan have some of the most violent crime, population density, and poverty and yet, the least amount of 3-1-1 calls. Further, SONYC sensor placement was not evenly distributed limiting noise comparisons in areas with lower than expected 3-1-1 call volume. Existing sensor technology employed by NYPD in areas such as the Bronx is only used by the NYPD and is not accessible to the public. This has drawn skepticism from the public and influences the public's trust with sensor technology and its applications. Although SONYC is not the only sound-capturing technology in NYC, this resource reveals the possible political and socio-economic barriers that shape how NYC measures and responds to noise.

Insights from the stakeholder interview acknowledge demonstrated need and potential for acoustic sensor technology and create a reference for future strategy. Framing each challenge as an opportunity for growth nurtured a relationship between NYC and SONYC that can forge a path for future noise mitigation technology.

There are many contributors of noise that have been aptly identified by NYC noise code and related studies. However, existing infrastructure and policy may enable sound disparity by way of inhibitory bureaucratic processes and conflicting policy that acts as an institutional barrier for the development of non-governmental noise mitigation technology. The interview with a member of SONYC's research team postulated the discrepancy between perceived noise vulnerability and SONYC sensor placement illustrated in the spatial analysis as due to logistical and bureaucratic limitations outside of their control. While SONYC was able to find some alternative routes, the process could've been more streamlined if NYC had existing internal structure that facilitated collaborative innovation.

SONYC's commitment to transparency and community involvement provides concrete techniques that could serve as a guide for government-level noise mitigation policy and technology. Technologies like ShotSpotter are already deployed in the city, but the lack of public accessibility to the data may damage the relationship the public have to sensor technology, and possibly law enforcement.

Technology bias, deployment bias, and a lack of transparency should serve as the first points of consideration when advocating for unbiased, quantitative data collection methods like acoustic sensor technology. The department's goals of optimization and integration of self-service tools for consumers may be outpaced by growing need and third-party technologies (OTI, 2022).

With this in mind, I put forth the following policy recommendations:

1. *Increase the transparency of existing NYC government-deployed sensor technology*.
    a. ShotSpotter is the only acoustic sensor technology found in this study employed by NYC government. Sensor locations and data are not public and are exclusively

used by the NYPD. A lack in transparency could foster distrust in future technology and perpetuate alleged misuse of the technology. Making sensor locations and data publicly accessible could advance research and build trust between NYC government, residents, visitors, and researchers. Policy makers could hold open forums, online or in-person, dedicated to the distribution and questions around technology in the city. Supporting on-the-ground advocate groups for data transparency and stakeholders through partnership and promotion would demonstrate an alignment with the people and the technology. Lobbying for data transparency from NYPD's ShotSpotter technology would demonstrate a vested interest in the people of NYC. Policy makers could also provide a list of resources or create a video or info graphics that explain what sensor technology is. Finally, inviting the public to participate in citizen science that interfaces with sensor data, like in SONYC's outreach, could help dispel skepticism and apprehension.

2. *Create or expand designated channels for ethical technological development, and research.*
    a. The Office of Technology and Innovation (OTI) is the acting liaison between NYC government departments and their technological needs. This study suggests the need for a designated sub-division for Technological Research and/or Data Ethics to address the ongoing development of new technologies, specifically acoustic sensor technology. The NSF funded SONYC to a technology for the benefit of understanding noise in NYC. If innovation is channeled through academic institutions who have the resources and expertise to develop in areas

like sensor technology, then the channels by which to connect this innovation with the city it serves should be made easier. Preparing channels for communication and direction between NYC government and external organizations in these specialties is essential for collaborative growth and maximizes the opportunity provided by funding.

3. *Update NYC Noise Code*

    a. NYC local law amended the Noise Code in 2005, nearly two decades ago. Since then, it has remained the baseline for noise control in the city. Primary contributors of noise pollution mentioned earlier in this study such as shifts in population, vehicular traffic, and seasonal tourism coupled with new trends in mobility necessitate an updated Noise Code for NYC. A comparative study of these changes could inform a new or revised baseline and approach to noise pollution in cities, better equipped to meet modern need. Additionally, using decibel *and* frequency to measure noise and its impact could address a deeper need for NYC citizens through an understanding of noise and how it travels. Policy makers could then design and implement strategies that include the acoustic design of the city, instead of just noise proximity. For example, construction projects are a high-decibel activity that has restrictions on operation time, and designated zones. This gives residents times to prepare their dwellings and themselves for this activity. Future development that considers how sound travels could mitigate the effects of high-decibel activity for those outside the directly impacted area.

Chapter 6: Conclusion & Future Research

Despite long-standing practice, the subjectivity of self-reported calls puts underrepresented neighborhoods at risk of noise disparity. Technology has the potential to fill qualitative gaps in current government data collection methods and promote equitable urban planning.

To address these concerns, this paper answers the following research questions:

1. How does NYC measure and respond to noise pollution?
    a. In the background provided in Chapter 2, I found that NYC measures noise pollution using self-reported 3-1-1 data and selective noise monitoring technology, like ShotSpotter. Consequences of noise violations include fines and a visit from local law enforcement.
2. What is the spatial relationship between noise pollution and socio-economic status in NYC?
    a. As shown in Figures 7-11 and 15, there is a possible relationship between socioeconomic status and 3-1-1 call volume where the areas with the lowest socio-economic status have the least number of calls, and mixed-income areas have the most number of calls, like Queens.
3. What is the spatial relationship between acoustic sensor locations and socio-economic status in NYC?
    a. There is an uneven distribution of SONYC sensors as shown in Figures 13 and 14. From the stakeholder interview, I found that this is due to limitations of

deployment determined by the compliance of government agencies like the DOT, despite best efforts.

4. What are the barriers to acoustic sensor implementation?
    a. From the perspective of SONYC, an academically based NSF-funded research project, barriers to implementation hinged primarily on logistical to political access. Funding, electrical outlets and cooperation from government entities played a significant role in the deployment and longevity of SONYC's acoustic sensor technology.

Although 3-1-1 calls and local law enforcement efforts mitigate some noise concerns, subjective noise reporting and sensor placement without proper offsets limit the breadth of equitable acoustic monitoring and abatement. A comparison of these data collection methods informs policy makers of the need for equitable distribution of sensor technology to optimize noise accountability in NYC and prioritize development in the appropriate NYC neighborhoods.

Limitations and Future Research

Limitations of this research include a limited scope of the area of study. Augmenting this research to include advanced mapping and greater range in data could provide greater insight to inform policy. Increasing the date range could provide a greater range of noise pollution changes over time in 3, 5 or 10 year increments within similar demographics. Additionally, increasing the radius of the area of study or including more locations could compare national or global trends. More advanced maps could add depth and detail to the data and analysis, where even an open-data, collaborative map of the variables identified in this study could contribute to data accessibility and citizen science.

Open-access Big Data is valuable as a quantitative offset and further, posits the need for an equitable distribution of data collection technology. Effective and inclusive acoustic monitoring informs intervention strategies that prioritize social equity in the development of Smart Cities. Future research in noise mitigation technology could explore:

- Vertical sound equity.
- A continuation of studies comparing decibel levels to 311 reports in high-vulnerability areas.
- Ethics and governance of continuous sound data collection.
- Strategies that balance law enforcement and citizen accountability.
- Noise impact evaluation based on frequency levels to determine sound range impact.

Including technologists and audio engineers would add further richness to this study in this area.

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Appendix

Interview Questions

- What was the permitting process like? What policy violations, if any, did you encounter?
- In what ways did the team find the most success in implementation, partnership or otherwise?
- What challenges came about along the way, and how did you address them?
- How did the research team navigate existing acoustic sensors in the city? Was this a conflict of interest?
- What was the ideal goal/outcome for SONYC, and how did that shift over time?
- How does SONYC's research "live on"?