

The National Transportation Noise Exposure Map

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Abstract

We describe the development and public availability of the National Transportation Noise Exposure Map with the goal of estimating population exposures to various noise levels at the census tract level in the United States. The map was created by overlaying the Bureau of Transportation Statistics' National Transportation Noise Map with 5-year block group population estimates from the American Community Survey, and aggregating exposed population estimates to the census tract level. Based on the exposure map, an estimated 94.9 million people (29.1 % of the total U. S. population) were exposed to ≥ 45 dB LAeq of transportation-related noise, and approximately 11.9 million (3.6 %) were exposed to ≥ 60 dB in the year 2020. The exposure maps indicate that the greatest population proportion and number of individuals exposed were in California, while generally the map illustrates high proportions of exposure for populations living along major U. S. roadways and in airport communities. The availability of this new exposure map will facilitate the integration of noise exposures into a variety of studies, including regional and national health impact assessments, epidemiologic, and environmental justice studies.

Introduction

Community noise has been linked to numerous negative health effects, including high annoyance (1,2), poor mental health (3), obesity (4), hypertension (5), heart disease (6–8), increased risk of diabetes (9), and sleep disturbance (10,11). Environmental noise affects some population groups more than others (12). Children exposed to high levels of noise experienced increased adrenaline and noradrenaline levels, annoyance, hyperactivity, high blood pressure, and poorer performance related to reading comprehension and memory skills and standardized

academic tests (13). Noise exposures among the elderly have been found to be associated with hypertension (14) and stroke (15). Assessment of population exposures to environmental noise is therefore important for understanding its role in the health of communities.

Mapping of environmental noise levels and assessment of population exposures is required of member states under the European Union's Environmental Noise Directive (END) (16). These maps and exposure estimates inform the EU's health impact assessments (17). Yet, nationwide population noise exposure mapping is typically not conducted for the United States due to the lack of city, state, and federal mandates and funding (18). Previous U. S. studies have largely focused on mapping noise exposures and health impacts for individual cities and regions (19–21). However, the U. S. EPA conducted a nationwide noise assessment in 1981, which estimated population exposures to various noise level categories (22). Although the EPA's assessment did not result in spatially explicit population exposures similar to those conducted under the END, the overall estimates of population numbers exposed to various noise level categories would enable use of noise exposure-response relationships to estimate various population health impacts, similar to how noise health impact assessments are conducted in the EU. More recent and promising efforts to map noise levels and exposures in the continental U. S., include a spatial model developed from noise monitoring data collected at various urban and rural sites, and principally at sites in national parks as required by the U. S. National Park Service (NPS) (23–26).

The U. S. Bureau of Transportation Statistics (BTS) developed the National Transportation Noise Map (NTNM), a detailed modeled noise map that covers the continental U. S., as well as the states of Alaska and Hawaii (27). The NTNM is intended to serve as a transportation planning tool, and therefore is based on modeled noise estimates from certain transportation sources, such as roadway, aviation, and rail traffic. While the BTS mention that the noise map data allow for viewing of potential exposures, the map itself only shows sound levels. While it is possible to overlay the NTNM with population data from the census to quantify and map population numbers exposed to different transportation noise level categories, thus far a national transportation noise exposure map is not widely available. A regularly updated and easily accessed U. S. noise exposure map would greatly facilitate health impact assessments, health effects studies that wish to incorporate estimated transportation-related noise exposure, and environmental justice studies.

In this paper we describe the development and public availability of national transportation exposure map for the U. S. with the goal of estimating population exposures to various noise levels at the census tract level. This map is based on an overlay of the most recently available NTNM and spatial population estimates from the American Community Survey (ACS) first at the census block group level for improved spatial accuracy, which is then aggregated to the census tract level for easier application to various population health studies. Based on this map, we present summaries of population numbers and proportions exposed to various noise levels at the state and national level. In the Discussion, we compare our findings with the EPA's 1981 noise assessment, and compare our spatial analysis approach to the modeling based on other recent noise modeling work for the U.S. We describe the potential limitations of the NTNM and our exposure map for those intending to use the exposure information for health impact assessment, epidemiologic, and environmental justice studies.

Methods

Spatial raster files of noise levels related to aviation, roadway and rail traffic were obtained from the BTS (28). These files were separated by state, with the most recent results available for the year 2020. The modeled noise levels in the NTNMM represent potential noise levels on an average day within the year 2020. The noise metric is the LAeq, the 24-hour equivalent A-weighted sound level at modeled receptor locations. Noise levels below 45 dBA LAeq are not included in the raster files, and pixels below this threshold are assigned missing values. The estimated noise levels at receptor locations from separate aviation, road, and rail models are acoustically summed to create a composite LAeq from the combined noise sources. We briefly describe the aviation, roadway, and rail models used below. Modeling details and assumptions are provided by the BTS (28).

Noise attributable to aviation was modeled in the NTNMM based on the Federal Aviation Administration (FAA) Aviation Environmental Design Tool (AEDT) model (29), using input from flight operation schedules and air traffic counts. Flight operations are averaged into a single typical average annual data, and include airports with an average of at least one daily flight departure. The input does not include airports that only have military operations, and does not include helicopter flights. The AEDT modeling approach uses a dynamic receptor grid spacing, in which an initial tenth of a mile grid around each airport is refined to a smaller spacing to produce a smooth noise contour is produced.

Noise attributable to roadway traffic was modeled in the Federal Highway Administration (FHWA) Traffic Noise Model (TNM) (30,31). TNM uses roadway traffic data in the form of average annual daily traffic (AADT) traffic counts from the FHWA's Highway Performance Monitoring System (HPMS) for various road types, including interstate highways, major and minor arterials, and major collector streets in both urban and rural areas. The traffic counts used by the model include automobiles and medium and heavy trucks. TNM is calculated for a 30 m grid of receptor locations.

Rail noise from conventional passenger trains is based on the Federal Transit Administration (FTA) Transit Noise and Vibration Impact Assessment Manual (32), while noise from high-speed rail is based on the Federal Railroad Administration (FRA) High Speed Ground Transportation Noise and Vibration Impact Assessment Manual (33). The models use train schedule and traffic data that is meant to be representative of a typical weekday. The year 2020 NTNMM also includes freight train traffic in the model. Rail noise is calculated for a 30 m receptor grid.

Population exposures to noise was estimated by overlaying the NTNMM noise raster map and census block group 5-year (2016-2020) estimates of total population from the American Community Survey (ACS) obtained through the Census Bureau API (34). The proportion of each census block group area that overlapped with LAeq noise categories of 45-50, 50-60, 60-70, 70-80, 80-90 and 90+ dB (greater than or equal applied to the lower bound of each category, and less than applied to the upper bound). This proportion was assumed to be the same as the proportion of the block group population exposed to the respective noise level category. The proportion of area in each block group with missing values for noise exposure was assumed to be equivalent to the proportion of the block group population that was exposed to less than LAeq 45 dB of transportation-related noise. For easier merging with census demographic information in future studies, the block group exposure estimates were aggregated

to the census tract level. This results in what we call the National Transportation Noise Exposure Map (NTNE Map).

Data processing and analyses were conducted in R (version 4.2.2) and the stars (0.6.0), sf (1.0.9), exactextractr (0.8.2), ggplot2 (3.4.0), and dplyr (1.0.10) packages. Data are provided as R sf data objects and as shapefiles at the link below. An online interactive version of the NTNE Map that allows for zooming and address/geolocation search is available at: <https://deohs.washington.edu/national-transportation-noise-exposure-map>

Results

Population numbers and proportions exposed to each of the noise level categories are presented by state and for the nation in Table 1. An estimated 94.9 million people (29.1 % of the total population) were exposed to ≥ 45 dB LAeq of transportation-related noise, and approximately 11.9 million (3.6 %) were exposed to ≥ 60 dB in the U.S. in 2020. The census tract-level map of the proportion exposed to LAeq ≥ 60 dB for the continental US is shown in Figure 1 (maps of Alaska and Hawaii are provided in Supplemental Info as Figures S1 and S2).

In terms of exposure and health risk, California had the highest proportion of its population (6.5% of population) that was exposed to transportation noise levels ≥ 60 dB LAeq (Figure 2). Completing the top-five states, the District of Columbia and Illinois had the next largest proportions exposed both with 5.8%, Massachusetts with 5.1%, and New York with 4.8% of its population exposed.

However, in terms of public health burden and the numbers of persons exposed to transportation noise, the more populated states tend to dominate the ranking (Figure 3). California had more than twice the number of people (approximately 2.6 million people) exposed to LAeq ≥ 60 dB transportation noise in 2020 than the next highest state, Texas with 1.0 million people exposed to these noise levels. The remaining top-five states in decreasing order of burden were New York, Illinois, and Florida.

The spatial patterns of tract-level exposures largely follow the underlying source geographic distributions. Comparing maps of successively higher exposure categories in Figures 1, S3 and S4 for population proportions exposed to transportation noise levels ≥ 60 , ≥ 70 and ≥ 80 dB LAeq, respectively reveals high noise exposures for those living along the network of highways and major roads across the U. S. As we zoom into specific regions, such as in the Seattle, King County region of Washington state, we can see the impact of airports on the proportion population exposed to noise. All three airports: Seattle-Tacoma International Airport, Boeing Field, and Renton Municipal Airport are located in the higher exposed regions (Figure S5), and the region most exposed to noise (in yellow color) is aligned with the north-south directions of the flight paths for Sea-Tac Airport.

Noise levels were found to vary considerably within census tracts due to the rapid noise attenuation with sound propagation distance. As an example, Figure S6 illustrates the distributions of sound levels for 30 m resolution pixels in the NTNMR raster map for each census tract within King County, Washington. The boxplots are ordered by increasing median noise

level in each tract, and yet large and small interquartile ranges can be observed through the range of median noise levels. The average interquartile range across the census tracts in this county is 7.2 dB LAeq. In contrast the average interquartile range across census block groups in the same county is less at 6.7 dB LAeq. This indicates that there can be considerable variation in noise levels within a census tract, and that there is less variation when using smaller census geographies such as the block group. In general, because of the variations in noise levels within either census tracts or block groups, the median may not be a good representation of noise exposure within these census boundaries. For this reason, we employed smaller block group level exposure assignments to compute numbers of exposed to separate noise level categories before aggregating these numbers to tract level estimates.

Table 1. Population numbers and proportions exposed to noise levels by state and total for all the United States.

State		Population	Exposed 45-50 dB		Exposed 50-60 dB		Exposed 60-70 dB	
Alabama	AL	4,893,186	418,152	8.55%	324,828	6.64%	96,446	1.97%
Alaska	AK	736,990	66,674	9.05%	54,250	7.36%	12,950	1.76%
Arizona	AZ	7,174,064	893,314	12.45%	783,902	10.93%	276,638	3.86%
Arkansas	AR	3,011,873	298,942	9.93%	206,325	6.85%	44,503	1.48%
California	CA	39,346,023	6,829,009	17.36%	6,445,125	16.38%	1,649,704	4.19%
Colorado	CO	5,684,926	707,212	12.44%	528,277	9.29%	120,248	2.12%
Connecticut	CT	3,570,549	344,770	9.66%	323,839	9.07%	69,262	1.94%
Delaware	DE	967,679	121,577	12.56%	82,422	8.52%	21,558	2.23%
District of Columbia	DC	701,974	167,757	23.90%	173,631	24.73%	34,819	4.96%
Florida	FL	21,216,924	2,629,069	12.39%	2,328,914	10.98%	511,497	2.41%
Georgia	GA	10,516,579	949,892	9.03%	732,199	6.96%	183,790	1.75%
Hawaii	HI	1,420,074	110,729	7.80%	105,595	7.44%	49,083	3.46%
Idaho	ID	1,754,367	168,594	9.61%	128,584	7.33%	22,158	1.26%
Illinois	IL	12,716,164	2,807,983	22.08%	2,949,760	23.20%	612,796	4.82%
Indiana	IN	6,696,893	926,319	13.83%	731,067	10.92%	165,155	2.47%
Iowa	IA	3,150,011	347,203	11.02%	269,234	8.55%	62,685	1.99%
Kansas	KS	2,912,619	452,019	15.52%	310,393	10.66%	47,108	1.62%
Kentucky	KY	4,461,952	461,338	10.34%	377,879	8.47%	124,493	2.79%
Louisiana	LA	4,664,616	455,010	9.75%	334,750	7.18%	75,619	1.62%
Maine	ME	1,340,825	61,772	4.61%	58,113	4.33%	18,077	1.35%
Maryland	MD	6,037,624	680,847	11.28%	589,586	9.77%	133,745	2.22%
Massachusetts	MA	6,873,003	1,099,693	16.00%	1,133,977	16.50%	282,649	4.11%
Michigan	MI	9,973,907	775,809	7.78%	735,507	7.37%	218,353	2.19%
Minnesota	MN	5,600,166	762,266	13.61%	560,400	10.01%	99,099	1.77%
Mississippi	MS	2,981,835	301,060	10.10%	195,670	6.56%	40,505	1.36%
Missouri	MO	6,124,160	697,696	11.39%	515,537	8.42%	113,043	1.85%
Montana	MT	1,061,705	126,116	11.88%	87,962	8.29%	17,093	1.61%
Nebraska	NE	1,923,826	266,504	13.85%	256,929	13.36%	42,991	2.23%
Nevada	NV	3,030,281	419,260	13.84%	358,163	11.82%	70,602	2.33%
New Hampshire	NH	1,355,244	77,571	5.72%	67,836	5.01%	19,261	1.42%
New Jersey	NJ	8,885,418	1,719,993	19.36%	1,421,097	15.99%	271,249	3.05%
New Mexico	NM	2,097,021	178,753	8.52%	128,770	6.14%	42,965	2.05%
New York	NY	19,514,849	3,698,438	18.95%	4,581,391	23.48%	692,324	3.55%
North Carolina	NC	10,386,227	636,173	6.13%	595,690	5.74%	216,742	2.09%
North Dakota	ND	760,394	110,813	14.57%	69,887	9.19%	11,204	1.47%
Ohio	OH	11,675,275	1,512,456	12.95%	1,142,243	9.78%	234,274	2.01%

Oklahoma	OK	3,949,342	460,858	11.67%	315,979	8.00%	57,939	1.47%
Oregon	OR	4,176,346	580,397	13.90%	491,015	11.76%	131,661	3.15%
Pennsylvania	PA	12,794,885	2,032,704	15.89%	1,666,183	13.02%	296,809	2.32%
Rhode Island	RI	1,057,798	107,514	10.16%	108,749	10.28%	24,919	2.36%
South Carolina	SC	5,091,517	421,412	8.28%	320,628	6.30%	77,393	1.52%
South Dakota	SD	879,336	82,623	9.40%	65,412	7.44%	13,673	1.55%
Tennessee	TN	6,772,268	566,253	8.36%	495,610	7.32%	125,322	1.85%
Texas	TX	28,635,442	4,109,907	14.35%	3,375,158	11.79%	781,061	2.73%
Utah	UT	3,151,239	427,757	13.57%	327,323	10.39%	98,253	3.12%
Vermont	VT	624,340	25,665	4.11%	24,833	3.98%	5,233	0.84%
Virginia	VA	8,509,358	980,822	11.53%	773,988	9.10%	207,411	2.44%
Washington	WA	7,512,465	963,339	12.82%	901,217	12.00%	196,713	2.62%
West Virginia	WV	1,807,426	101,675	5.63%	79,158	4.38%	22,586	1.25%
Wisconsin	WI	5,806,975	612,177	10.54%	501,934	8.64%	127,510	2.20%
Wyoming	WY	581,348	68,324	11.75%	54,478	9.37%	8,685	1.49%
Total		326,569,308	43,822,211	13.42%	39,191,398	12.00%	8,879,860	2.72%

Table 1. (Continued).

State		Exposed 70-80 dB		Exposed 80-90 dB		Exposed 90+ dB	
Alabama	AL	22,289	0.46%	3,021	0.06%	262	0.01%
Alaska	AK	2,349	0.32%	56	0.01%	4	0.00%
Arizona	AZ	40,748	0.57%	9,166	0.13%	89	0.00%
Arkansas	AR	11,045	0.37%	2,165	0.07%	167	0.01%
California	CA	672,518	1.71%	249,542	0.63%	3,014	0.01%
Colorado	CO	27,845	0.49%	4,162	0.07%	178	0.00%
Connecticut	CT	23,507	0.66%	3,498	0.10%	237	0.01%
Delaware	DE	5,867	0.61%	375	0.04%	47	0.00%
District of Columbia	DC	5,229	0.74%	364	0.05%	61	0.01%
Florida	FL	149,988	0.71%	24,145	0.11%	506	0.00%
Georgia	GA	42,151	0.40%	9,351	0.09%	436	0.00%
Hawaii	HI	11,944	0.84%	855	0.06%	3	0.00%
Idaho	ID	4,568	0.26%	510	0.03%	30	0.00%
Illinois	IL	99,178	0.78%	16,629	0.13%	2,847	0.02%
Indiana	IN	34,426	0.51%	5,284	0.08%	545	0.01%
Iowa	IA	16,768	0.53%	2,285	0.07%	242	0.01%
Kansas	KS	16,158	0.55%	1,320	0.05%	252	0.01%
Kentucky	KY	24,682	0.55%	3,598	0.08%	233	0.01%
Louisiana	LA	19,955	0.43%	1,245	0.03%	170	0.00%
Maine	ME	3,111	0.23%	148	0.01%	24	0.00%
Maryland	MD	38,292	0.63%	6,140	0.10%	271	0.00%
Massachusetts	MA	58,093	0.85%	10,560	0.15%	708	0.01%
Michigan	MI	43,531	0.44%	8,085	0.08%	168	0.00%
Minnesota	MN	35,130	0.63%	2,813	0.05%	400	0.01%
Mississippi	MS	9,020	0.30%	794	0.03%	132	0.00%
Missouri	MO	36,880	0.60%	5,263	0.09%	401	0.01%
Montana	MT	2,844	0.27%	177	0.02%	38	0.00%
Nebraska	NE	9,189	0.48%	1,835	0.10%	236	0.01%
Nevada	NV	19,773	0.65%	5,942	0.20%	19	0.00%
New Hampshire	NH	4,712	0.35%	124	0.01%	18	0.00%
New Jersey	NJ	72,672	0.82%	8,336	0.09%	924	0.01%
New Mexico	NM	6,768	0.32%	1,399	0.07%	42	0.00%
New York	NY	191,507	0.98%	46,899	0.24%	2,277	0.01%
North Carolina	NC	41,654	0.40%	3,879	0.04%	150	0.00%
North Dakota	ND	2,894	0.38%	153	0.02%	48	0.01%
Ohio	OH	68,199	0.58%	9,965	0.09%	1,129	0.01%

Oklahoma	OK	18,672	0.47%	1,970	0.05%	245	0.01%
Oregon	OR	23,035	0.55%	2,815	0.07%	241	0.01%
Pennsylvania	PA	81,433	0.64%	8,828	0.07%	1,729	0.01%
Rhode Island	RI	6,601	0.62%	278	0.03%	43	0.00%
South Carolina	SC	18,937	0.37%	1,402	0.03%	144	0.00%
South Dakota	SD	3,217	0.37%	203	0.02%	15	0.00%
Tennessee	TN	25,511	0.38%	4,691	0.07%	154	0.00%
Texas	TX	212,888	0.74%	43,813	0.15%	1,781	0.01%
Utah	UT	20,427	0.65%	5,504	0.17%	202	0.01%
Vermont	VT	1,011	0.16%	30	0.00%	6	0.00%
Virginia	VA	53,360	0.63%	7,071	0.08%	574	0.01%
Washington	WA	43,657	0.58%	5,769	0.08%	248	0.00%
West Virginia	WV	6,559	0.36%	647	0.04%	51	0.00%
Wisconsin	WI	30,739	0.53%	3,110	0.05%	245	0.00%
Wyoming	WY	1,815	0.31%	114	0.02%	21	0.00%
Total		2,423,347	0.74%	536,327	0.16%	22,007	0.01%

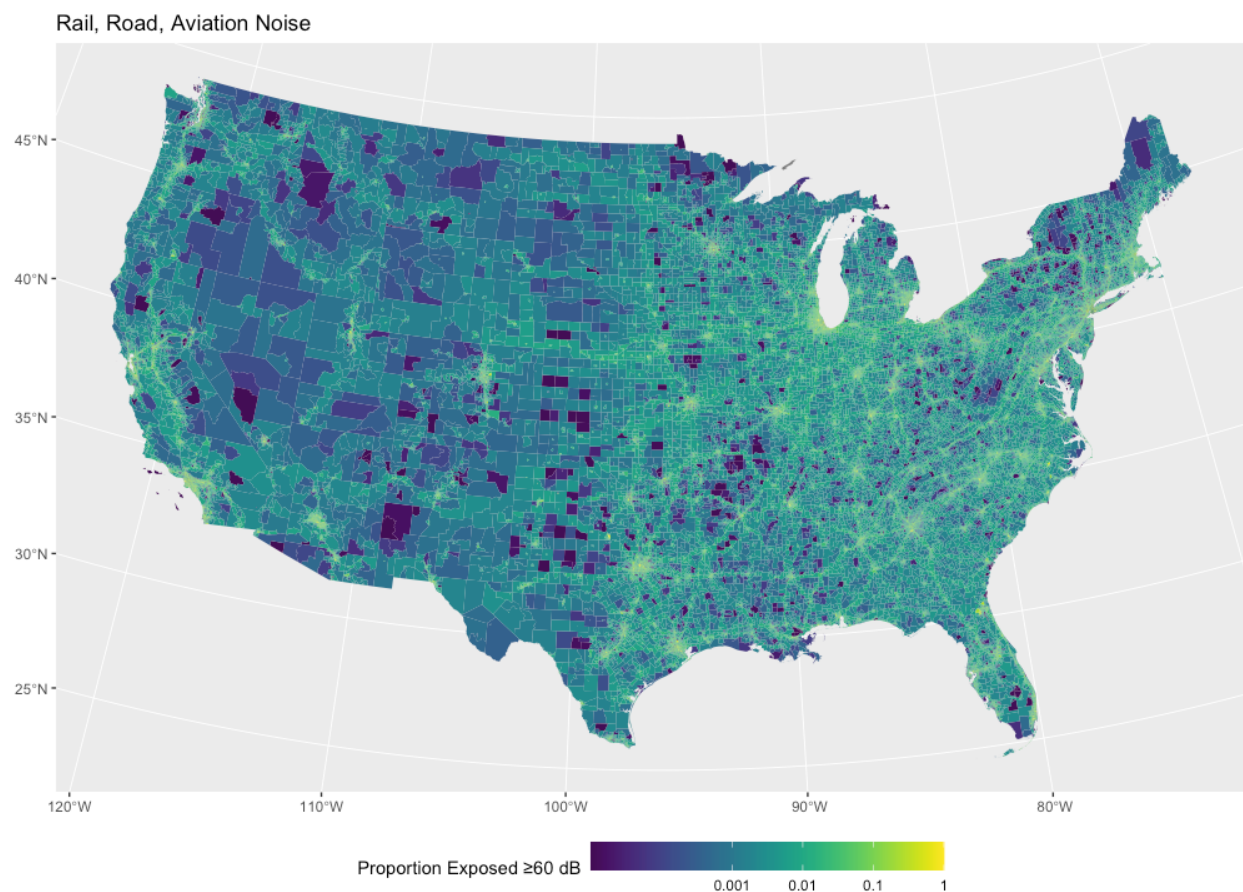


Figure 1. The National Transportation Noise Exposure Map for the continental United States in 2020.

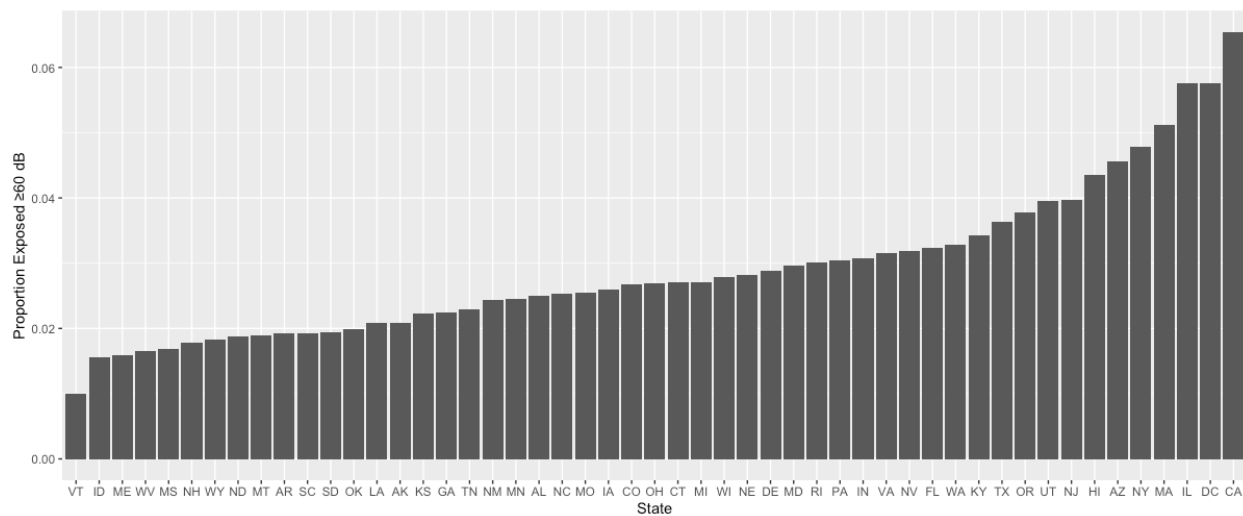


Figure 2. Ranking of the proportion of population with transportation noise exposures states ≥ 60 dB by state

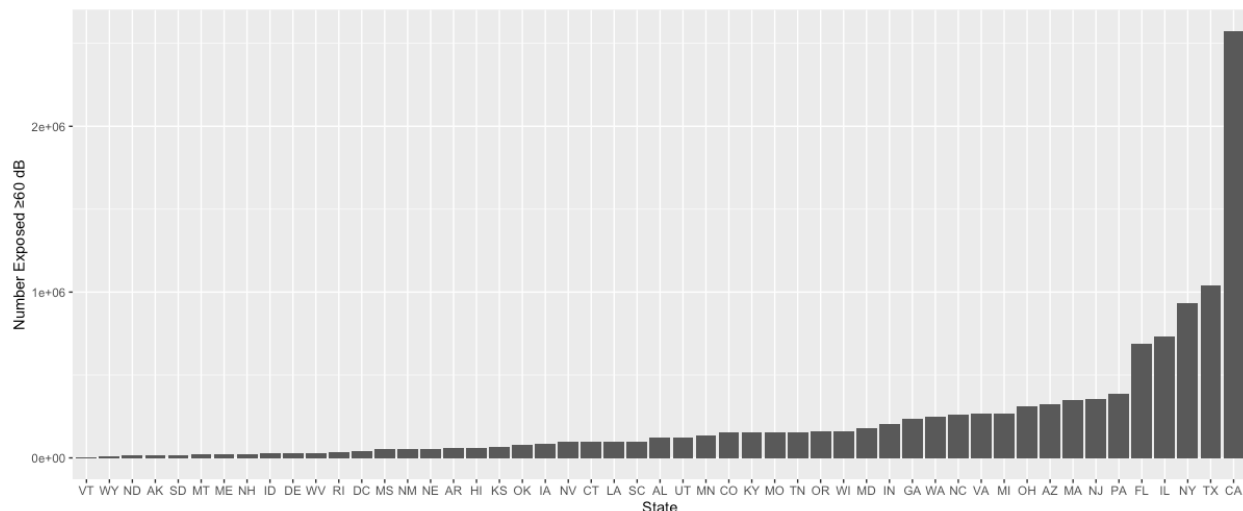


Figure 3. Ranking of the number of people with transportation noise exposures states ≥ 60 dB by state

Discussion

This paper presents methods used to develop the NTNE Map, a population exposure map for transportation-related noise at the census tract-level for the U. S. Our map focuses on transportation-related noise, which is a major contributor to noise in populated areas. This map benefits from methodological improvements over previous national noise exposure modeling approaches, notably in the use of the NTN and the collective noise source data and modeling efforts of federal aviation, road, and rail agencies. These models utilize transportation scheduling and count data, noise emissions, and sound propagation principles. This differs from other studies that utilize spatial models fit to sound monitoring data (19–21), which depend on the availability and the generalizability of sampling locations for sound monitoring data. In some cases, entire states may not have appropriate sound monitoring data to fit spatial land use regression type sound models (see Figure 1 in (23)). Also, compared to previous studies that have used the BTS NTN (35), our map provides some potential methodological improvements, including the computation of block group level population exposures before aggregation to the census tract, which allows for better accounting of uneven spatial distributions of population within census tracts, as well as the variations in noise that exist within tracts. Additionally, our methods retain the population proportions and numbers exposed to different noise level categories, which is useful for applying noise exposure-response functions in health impact assessments. Use zonal statistics such as the median non-missing noise level within a census tract computed in other studies (26) may not be appropriate for use in health impact assessments due to the large variation in noise within tract.

The previous EPA 1981 nationwide exposure assessment estimated that 23.4% of the U. S. population was exposed to $L_{dn} \geq 60$ dB, 2.9 % was exposed to ≥ 70 dB, and 0.05 % was exposed to ≥ 80 dB (22). These population exposure percentages were based on the L_{dn} noise metric, which accounts for a 10 dB nighttime penalty. Based on our NTNE Map, 3.6 %, 0.9 %, and 0.2 % were exposed to those same noise level categories in 2020, but for the L_{Aeq} noise

metric. Direct comparisons are difficult because the Ldn metric will be higher than a LAeq due to the nighttime penalty incorporated in the Ldn. Also, EPA's assessment includes transportation related exposures, as well as other community noise sources and occupational noise exposure. Nevertheless, we notice that at the highest ≥ 80 dB category, we estimate a greater population proportion exposed than EPA's 1981 assessment, which potentially highlights the disproportionately high levels of exposures for those that live closest to major transportation routes and hubs.

The disproportionate exposure to community noise has been previously studied by others, who have found that nighttime noise levels may be higher in urban neighborhoods with predominately black residents compared to neighborhoods with predominately white residents, and higher nighttime noise levels in neighborhoods with a larger percentage of the residents living below the federal poverty threshold (26). This previous work mentions potential explanations for such disparity in exposure, which may have to do with historical land use issues related to the types of noise sources (e.g., airplanes and roadway traffic) that exist in particular neighborhoods. This work also notes that ambient noise exposures may not fully represent household and personal exposures and health impacts, which are also affected by housing quality and noise mitigation measures, occupational noise exposure, and co-exposures such as to air pollution, and co-morbidities that may place individuals at greater risk for noise-related health issues.

Other researchers who have used the BTS transportation noise map have also found evidence of disparate noise exposures. A study that overlaid the noise map on the location of U. S. public schools found that high exposure was related to greater likelihood of students eligible for free/reduced meals, greater likelihood to be Hispanic, black, or Asian/Pacific Islander students (36). These authors have also used the transportation noise map to look more broadly at environmental justice issues, and have found that noise is associated with lower socioeconomic status generally, and affects greater proportions of Hispanic, black, Asian, Pacific Islander, and middle/working-aged groups (35). These studies illustrate the potential for a regularly updated and easily accessible national transportation exposure map, like NTNE Map, to be used in more studies to understand the context and causes for transportation noise exposure inequity.

Because the BTS produces regular updates to the NTNM for trend analyses by transportation agencies, there is an opportunity for regular updating of exposure estimates for our NTNE Map to assess trends in exposure over time. Currently, model results for the NTNM are available for the years 2016, 2018, and 2020. This may facilitate epidemiologic studies that require longitudinal noise exposures, as well as health impact assessments estimating potential changes in noise-related health outcomes over time due to changes in transportation.

There are potential limitations of the national exposure map that should be considered for exposure assessments in subsequent studies. First, the map only considers transportation-related noise. Thus, it is likely an underestimate of community noise exposures, which include exposures to other noise sources such as the soundscape of the natural environment, people noise, entertainment, construction, commercial and industrial, machinery, etc. Moreover, not all transportation-related sources are included in the noise models. Notably, military airport traffic is not included in the aviation noise model. Also, maritime traffic noise is not included in the model. Therefore, exposures are probably not accurate in the map for residents living near military airports or maritime ports and their traffic routes. This is an important limitation for

environmental justice studies, as both military airports and port communities have loud noise sources that will not be well-represented on the map. Second, as a neighborhood tract level ambient transportation noise exposure map, it does not account for individual level factors that may affect exposure, such as housing conditions noise mitigation efforts, work exposure, mobility across varying noise micro environments, etc. Efforts are need to compare measured personal noise exposures to noise exposures assigned to their residential census tract location or time spent in different tracts due to personal mobility. Third, the mapped exposures are computed using the LAeq noise metric, yet many noise exposure-response functions are based on the Ldn or Lden noise metrics, which incorporate dB penalties during evening and nighttime hours. Therefore, use the LAeq from the noise map in some exposure-response functions will likely underestimate potential population health impacts. Fourth, although the individual noise models for aviation, roadway, and rail traffic have undergone some validation, there is still a need for validation studies to determine the relationships between modeled sum of transportation-related noise levels and real-world measured community noise levels.

Despite these limitations, the NTNMM has been found to be useful in previous studies. With the availability of our new NTNE Map that characterizes population exposures at the census tract level, we hope that it will be easier for groups to integrate noise exposures into a variety of studies, including regional and national health impact assessments, environmental justice studies, and epidemiologic studies that consider noise as either primary exposures or co-exposures of interest.

References

1. Schultz TJ. Synthesis of social surveys on noise annoyance. *The Journal of the Acoustical Society of America*. 1978 Aug;64(2):377–405.
2. Guski R, Schreckenberg D, Schuemer R. WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Annoyance. *International Journal of Environmental Research and Public Health*. 2017 Dec;14(12):1539.
3. Gong X, Fenech B, Blackmore C, Chen Y, Rodgers G, Gulliver J, et al. Association between Noise Annoyance and Mental Health Outcomes: A Systematic Review and Meta-Analysis. *International Journal of Environmental Research and Public Health*. 2022 Jan;19(5):2696.
4. Cramer J, Therning Jørgensen J, Sørensen M, Backalarz C, Laursen JE, Ketznel M, et al. Road traffic noise and markers of adiposity in the Danish Nurse Cohort: A cross-sectional study. *Environmental Research*. 2019 May 1;172:502–10.
5. van Kempen E, Babisch W. The quantitative relationship between road traffic noise and hypertension: a meta-analysis. *Journal of Hypertension*. 2012 Jun;30(6):1075.
6. Roswall N, Raaschou-Nielsen O, Ketznel M, Gammelmark A, Overvad K, Olsen A, et al. Long-term residential road traffic noise and NO2 exposure in relation to risk of incident myocardial infarction – A Danish cohort study. *Environmental Research*. 2017 Jul 1;156:80–6.

7. Babisch W. Updated exposure-response relationship between road traffic noise and coronary heart diseases: A meta-analysis. *Noise and Health*. 2014 Jan 1;16(68):1.
8. Münzel T, Gori T, Babisch W, Basner M. Cardiovascular effects of environmental noise exposure. *European Heart Journal*. 2014 Apr 1;35(13):829–36.
9. Zare Sakhvidi MJ, Zare Sakhvidi F, Mehrparvar AH, Foraster M, Dadvand P. Association between noise exposure and diabetes: A systematic review and meta-analysis. *Environmental Research*. 2018 Oct 1;166:647–57.
10. Muzet A. Environmental noise, sleep and health. *Sleep Medicine Reviews*. 2007 Apr 1;11(2):135–42.
11. Hume KI, Brink M, Basner M. Effects of environmental noise on sleep. *Noise and Health*. 2012 Nov 1;14(61):297.
12. Kamp I van, Davies H. Noise and health in vulnerable groups: A review. *Noise and Health*. 2013 May 1;15(64):153.
13. Stansfeld S, Clark C. Health Effects of Noise Exposure in Children. *Curr Envir Health Rpt*. 2015 Jun 1;2(2):171–8.
14. Jarup L, Babisch W, Houthuijs D, Pershagen G, Katsouyanni K, Cadum E, et al. Hypertension and Exposure to Noise Near Airports: the HYENA Study. *Environ Health Perspect*. 2008 Mar;116(3):329–33.
15. Sørensen M, Hvidberg M, Andersen ZJ, Nordsborg RB, Lillelund KG, Jakobsen J, et al. Road traffic noise and stroke: a prospective cohort study. *Eur Heart J*. 2011 Mar;32(6):737–44.
16. Murphy E, King EA. Strategic environmental noise mapping: Methodological issues concerning the implementation of the EU Environmental Noise Directive and their policy implications. *Environment International*. 2010 Apr 1;36(3):290–8.
17. European Environment Agency. Environmental noise in Europe — 2020 [Internet]. [cited 2023 Jan 30]. Available from: <https://www.eea.europa.eu/publications/environmental-noise-in-europe>
18. Hammer MS, Swinburn TK, Neitzel RL. Environmental Noise Pollution in the United States: Developing an Effective Public Health Response. *Environmental Health Perspectives*. 2014 Feb;122(2):115–9.
19. Lee EY, Jerrett M, Ross Z, Coogan PF, Seto EYW. Assessment of traffic-related noise in three cities in the United States. *Environmental Research*. 2014 Jul 1;132:182–9.
20. Seto EYW, Holt A, Rivard T, Bhatia R. Spatial distribution of traffic induced noise exposures in a US city: an analytic tool for assessing the health impacts of urban planning decisions. *Int J Health Geogr*. 2007 Jun 21;6(1):24.

21. Kim M, Chang SI, Seong JC, Holt JB, Park TH, Ko JH, et al. Road Traffic Noise: Annoyance, Sleep Disturbance, and Public Health Implications. *American Journal of Preventive Medicine*. 2012 Oct 1;43(4):353–60.
22. US EPA. Noise in America: the Extent of the Noise Problem [Internet]. 1981 [cited 2023 Jan 30]. Report No.: 550/9-81–101. Available from: <https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockkey=P100QCFD.txt>
23. Sherrill KR. GIS Metrics - Soundscape Modeling, Standard Operating Procedure [Internet]. National Park Service, Fort Collins, Colorado; 2012. Report No.: NPS/NRSS/IMD/NRR—2012/596. Available from: https://www.people.iup.edu/rhoch/ClassPages/IntroGIS/SOPs/GISMetricsSoundscapeModelingSOP_nrss.pdf
24. Mennitt DJ, Fristrup KM. Influence factors and spatiotemporal patterns of environmental sound levels in the contiguous United States. *Noise Control Engineering Journal*. 2016 May 1;64(3):342–53.
25. Mennitt D, Sherrill K, Fristrup K. A geospatial model of ambient sound pressure levels in the contiguous United States. *The Journal of the Acoustical Society of America*. 2014 May;135(5):2746–64.
26. Casey JA, Morello-Frosch R, Mennitt DJ, Fristrup K, Ogburn EL, James P. Race/Ethnicity, Socioeconomic Status, Residential Segregation, and Spatial Variation in Noise Exposure in the Contiguous United States. *Environ Health Perspect*. 2017 Jul 25;125(7):077017.
27. U.S. Department of Transportation, Bureau of Transportation Statistics. National Transportation Noise Map Documentation [Internet]. 2020. Available from: <https://doi.org/10.21949/1520433>
28. Bureau of Transportation Statistics. National Transportation Noise Map [Internet]. [cited 2023 Jan 30]. Available from: <https://www.bts.gov/geospatial/national-transportation-noise-map>
29. US Department of Transportation Federal Aviation Administration. Aviation Environmental Design Tool (AEDT) Version 3b Technical Manual [Internet]. 2019. Report No.: DOT-VNTSC-FAA-19-03. Available from: https://aedt.faa.gov/Documents/AEDT3b_TechManual.pdf
30. U.S. Department of Transportation Federal Highway Administration. Federal Highway Administration's Traffic Noise Model (FHWA TNM®), Version 1.0 - Technical Manual [Internet]. 1998. Report No.: FHWA-PD-96-010 DOT-VNTSC-FHWA-98-2. Available from: https://www.fhwa.dot.gov/environment/noise/traffic_noise_model/old_versions/tnm_version_10/tech_manual/
31. U.S. Department of Transportation Federal Highway Administration. TNM V2.5 Update Sheet [Internet]. 2004. Available from: https://www.fhwa.dot.gov/environment/noise/traffic_noise_model/tnm_v25/tech_manual/part1.cfm

32. Federal Transit Administration. Transit Noise and Vibration Impact Assessment Manual [Internet]. 2018. Report No.: FTA Report No. 0123. Available from: https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/118131/transit-noise-and-vibration-impact-assessment-manual-fta-report-no-0123_0.pdf
33. U.S. Department of Transportation Federal Railroad Administration. High-Speed Ground Transportation Noise and Vibration Impact Assessment [Internet]. 2012. Report No.: DOT/FRA/ORD-12/15. Available from: https://railroads.dot.gov/sites/fra.dot.gov/files/fra_net/2680/20120220_FRA_HSR_NV_Manual_FINAL_102412.pdf
34. US Census Bureau. American Community Survey 5-Year Data (2009-2021) [Internet]. Census.gov. 2023 [cited 2023 Jan 30]. Available from: <https://www.census.gov/data/developers/data-sets/acs-5year.html>
35. Collins TW, Nadybal S, Grineski SE. Sonic injustice: Disparate residential exposures to transport noise from road and aviation sources in the continental United States. *Journal of Transport Geography*. 2020 Jan 1;82:102604.
36. Collins TW, Grineski SE, Nadybal S. Social disparities in exposure to noise at public schools in the contiguous United States. *Environmental Research*. 2019 Aug 1;175:257–65.