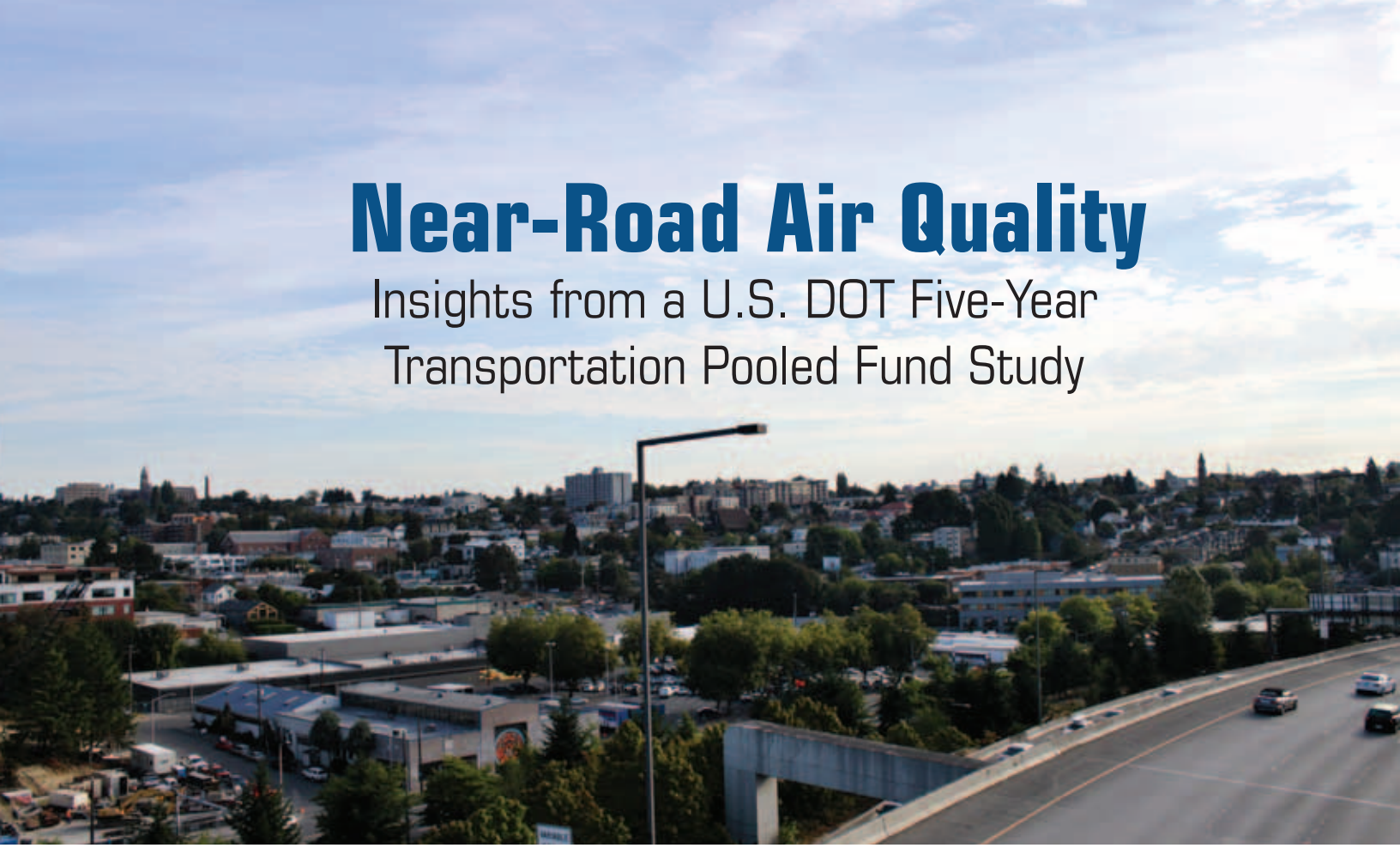
Near-Road Air Quality

Insights from a U.S. DOT Five-Year Transportation Pooled Fund Study



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Above: The Atlantic neighborhood of Seattle, Washington, can be seen from the José Rizal Bridge. This and surrounding neighborhoods were subject to redlining—a discriminatory practice occurring throughout the 20th century that rated communities of color and lower-income neighborhoods as "high risk" for investment. Among redlining's many consequences is poor air quality in neighborhoods that often were (and still are) chosen as locations for high-traffic freeways.

Air pollution in urban areas has been closely connected with vehicle use for more than half a century. Emissions from cars, trucks, and other vehicles are harmful on their own, and they combine in the atmosphere with air pollutants from other sources to form regional-scale pollution that includes a mix of particulate matter (PM), ground-level ozone (O_3), nitrogen dioxide (NO_2), and other substances. Pollutants directly emitted by vehicles—from exhaust, wear from brake pads and tires, or dust from disturbing the road surface—are of special concern in areas adjacent to heavily traveled roads.

Research shows that substantial traffic—especially diesel-powered trucks and buses—can create pollution hot spots within a few hundred meters of major roads. Example hot spot pollutants of concern are the soot emitted from diesel vehicle exhaust, often referred to as diesel PM, oxides of nitrogen [both nitric oxide (NO) and NO_2], carbon monoxide (CO), and toxics such as benzene.

Near-road hot spots are of particular concern, given the growing awareness of the need to address environmental justice and community-based air quality. Communities near heavily traveled roads often are more economically disadvantaged and have a higher proportion of minority residents than communities in other settings.

Near-road air quality is an environmental justice concern.

Many factors govern the formation of near-road pollution hot spots. For example, traffic volumes and speeds, the number and ages of cars and trucks on the road, roadway design, topography, and local meteorology all play a role in determining whether near-road air pollution is worse than in surrounding neighborhoods. Since near-road pollution is a health concern and the conditions

Photo: National Association of City Transportation Officials

To mitigate the health impacts of near-road pollution, the U.S. Environmental Protection Agency mandates air quality impact evaluations of proposed highway projects.

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Exhaust fumes cloud the scene of a traffic jam along the New Jersey Turnpike. Even though fleet turnover—when older, higher-polluting vehicles are replaced with newer, lower-polluting vehicles—plays a big role in decreasing near-road air pollution, the particulate matter found in vehicle exhaust is still hazardous to human health.

under which hot spots form vary, the U.S. Environmental Protection Agency (EPA) mandates evaluation of proposed highway project impacts and measurement of near-road pollution levels.

In recognition of the importance of addressing near-road air pollution, eight state and federal agencies pooled their research efforts on the topic, obtaining and evaluating an unprecedented amount of near-road air quality data. From 2014 through 2019, the agencies formed the Near-Road Air Quality Transportation Pooled Fund (TPF), sponsored by the U.S. Department of Transportation (DOT), and selected Sonoma Technology, Inc., to provide planning and research support.

The 2014 launch of the EPA national requirement for near-road air quality monitoring sparked the formation of the TPF. The EPA mandate helped create the first-ever widespread U.S. air measurement network to assess near-road conditions. TPF work took place from 2014 to 2019, directly overlapping the network's launch, and took advantage of the availability of this unique data set.

The Near-Road Air Quality TPF research program included participants from the U.S. Federal Highway Administration (FHWA), as well as from Arizona, California, Colorado, Ohio, Texas, Virginia, and Washington State DOTs. STI researchers carried out the technical work program, while Washington State DOT served as lead agency and managed overall research.

Even though TPF state DOT partners represented just seven of the 50 states, their work evaluated data from the entire national network of EPA-mandated near-road air quality measurement sites located next to major highways across the United States. As of late 2019, this network included nearly 60 U.S. metropolitan areas. Researchers also completed in-depth case studies of various metropolitan areas, based on air quality, traffic, and site characteristics, independent of whether the sites were in TPF sponsor states. This article highlights the TPF research findings.

Near-Road Pollutant Concentration Findings

The research confirmed some well-understood insights, produced some surprise "good news" findings, and found long-term trends headed in a positive direction. TPF research showed unequivocally that CO is no longer a near-road problem. For every mile a new vehicle is driven today, it emits a tiny fraction of the CO emitted by similar vehicles built decades ago.

As older vehicles are retired from the fleet, the turnover to cleaner vehicles continuously reduces CO and other tailpipe pollutants. The result is a remarkable pollution-control success story: CO hot spots have disappeared adjacent to major U.S. roads. Though expected, the research partners found it important to document this good news because CO remains a hot spot assessment requirement for highway projects.

Somewhat surprisingly—and also good news—the research showed that virtually all near-road NO_2 concentrations fell below existing health-based air quality standards. When TPF work began, near-road NO_2 had not yet been measured extensively, and, EPA had recently adopted new National Ambient Air Quality Standards (NAAQS) for NO_2 with a focus on near-road settings, under authority of the U.S. Clean Air Act. NAAQS are EPA's health-based air quality standards, or concentration values at or below which public health is protected. Until the near-road monitoring network was established, it was unclear whether many areas had NO_2 concentrations of concern.

With those findings in mind, researchers focused on assessing the concentration of very small particles: particulate matter less than 2.5 microns in diameter, or $PM_{2.5}$ (for comparison, a human hair is about 70 microns in diameter). $PM_{2.5}$ is one of the most important air pollutants from a health perspective—its small size means it can penetrate deeply into the respiratory system, and $PM_{2.5}$ exposure can increase respiratory problems, cancer incidence, and risk of death.

The work of the TPF characterized near-road $PM_{2.5}$ conditions across the United States, identified areas with concentrations above health-based benchmarks, identified

relationships between concentrations and roadway characteristics, observed and forecasted trends, and compared both modeled and measured concentrations. The research findings offer a positive outcome: Most areas have $PM_{2.5}$ concentrations below NAAQS, and emission trends suggest that future conditions will continue to improve.

The material that follows illustrates findings using data from 2016 as an example. Generally, findings illustrated here were consistent across analysis years covered by TPF assessments. For research purposes, researchers compared measured data to NAAQS levels. Each NAAQS includes an averaging period, the number of hours that the value represents. For example, for CO there are two standards: 1-hour and 8-hour. The 8-hour standard is the average value over eight consecutive hours. In their analysis, researchers focused on key averaging periods of interest for each pollutant: 8-hour for CO, 1-hour for NO_2, and 24-hour for $PM_{2.5}$. They also evaluated concentrations across annual and multiyear time windows.

These comparisons are for context only and are not meant to assess whether an area officially meets NAAQS; EPA makes those official determinations. Table 1 highlights these findings.

CARBON MONOXIDE

TPF findings reinforce that CO emissions control is a U.S. success story and that CO concentrations are well below levels of concern. The 2016 8-hour CO concentrations at near-road sites ranged up to a maximum of 3.5 parts per million (ppm). For comparison, the 8-hour NAAQS is 9 ppm.

NITROGEN DIOXIDE

TPF findings illustrate that near-road NO_2 concentrations are not a concern according to NAAQS. In 2016, only four 1-hour NO_2 values exceeded the EPA standard of 100 parts per billion (ppb). There were no values above the NAAQS at the 98th percentile for the data; EPA uses a three-year average of 98th percentile data when determining whether an area violates air standards.

$PM_{2.5}$

TPF findings showed that although there were exceedances of the $PM_{2.5}$ standard, they were rare and limited to a few locations. In 2016, $PM_{2.5}$ was monitored at 42 sites, six of which had two monitors. There were 29 monitors that measured $PM_{2.5}$ hourly; the remaining 19 sampled $PM_{2.5}$ on a 24-hour basis at various frequencies (daily, or one out of every three or six days). EPA uses the 98th percentile value of daily data to assess whether an area violates the standard; this is roughly equivalent to ignoring the seven days of the year with the highest concentrations.

In 2016, 24-hour $PM_{2.5}$ concentrations exceeded the NAAQS value (35 µg/m³) in 19 instances. Only Ontario, California, had a 98th-percentile concentration that exceeded 35 µg/m³, however.

Background Concentration Assessments

One TPF objective was to better understand air pollution differences between near-road and surrounding areas. In simple terms, the roadway pollution contribution, or increment, is calculated by subtracting a background concentration from a measured near-road concentration.

Numerous practical challenges make background concentration estimation difficult. Most urban areas have more than one background monitor and identifying the "true" background concentration at the near-road site is difficult. More monitors in an area can provide confirmation of the background concentration if they agree, or they can provide differing values. Discerning which background concentration to use is a critical step in a hot spot analysis.

A key issue the TPF research examined was to understand how big an error might be introduced in hot spot analyses by inadvertently assigning an incorrect background concentration value at a particular transportation project site. One way this issue was dealt with was to assess how background values varied across 45 core-based statistical areas (CBSAs). Since $PM_{2.5}$ hot spot analyses use three years of data, TPF analyses used data from 2015 to 2017 to identify the range of concentrations within each CBSA.

For about half of the CBSAs, there was not a large difference in background concentrations from one monitor to another. However, in the other half of the CBSAs, the range of background values varied substantially: The highest measured background was anywhere from 14 to 106 percent above the lowest background concentration, depending on monitor choice.

Figure 1 shows the range of background values by CBSA. As shown in Figure 1, some areas have many more background monitors than others. More monitors generally mean better differentiation of background pollution differences across a given metropolitan area. If a CBSA has big concentration differences among its monitors, however, there is a higher risk of error estimating background concentration if an analyst incorrectly chooses which monitor or monitors to use.

The TPF findings help bound uncertainty for each of the CBSAs assessed. Bounding is important because the larger the range of potential background values, the greater the need to carefully assess which monitors to use when estimating a representative background concentration.

TABLE 1 Amount of 2016 Pollutant Data at or Below EPA Air Quality Standards

Pollutant and NAAQS Averaging Period	Total Number of 2016 Measurements	Number Above NAAQS	Values ≤ NAAQS (%)	NAAQS
CO (8-hour values)	387,310	0	100%	9 ppm
NO_2 (1-hour values)	547,398	4	99.9993%	100 ppb
$PM_{2.5}$ (24-hour values)	11,459	19	99.83%	35 µg/m³

NOTE: NAAQS = National Ambient Air Quality Standards; CO = carbon monoxide; NO_2 = nitrogen dioxide; $PM_{2.5}$ = atmospheric particulate matter with diameter less than 2.5 micrometers; ppm = parts per million; ppb = parts per billion; µg/m³ = micrograms per cubic meter air.

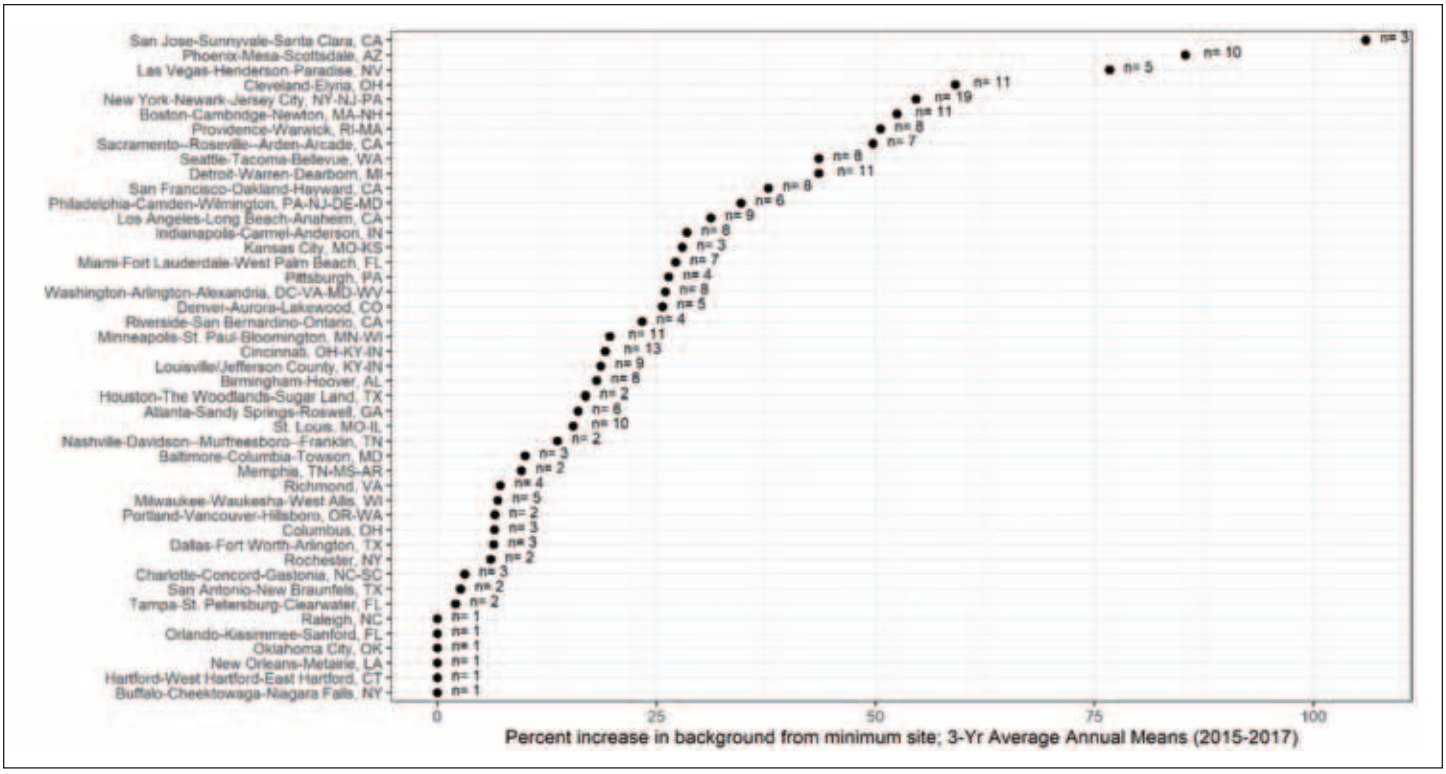

FIGURE 1 **Percent increase in $PM_{2.5}$ background concentrations that might be estimated in a metropolitan area, based on monitor choice. (Note: n = number of monitors in each core-based statistical area, excluding the near-road monitor.)**

$PM_{2.5}$ Increment Findings

The following $PM_{2.5}$ increment findings use 2017 data from 20 sites with nearby background monitors and minimal confounding factors such as other major nearby pollution sources. The upper bound of $PM_{2.5}$ increments at the 20 sites was 2.0 µg/m³ (Figure 2). Values shown in Figure 2 were computed using two methods to select and weight monitors measuring background concentrations: an inverse distance weighting approach that used multiple monitors but weighted the closest sites more heavily and a nearest monitor calculation using one site.

Three sites had an increment greater than 1.4 µg/m³; monitors at these sites were less than 10 meters from the road. The findings show that the maximum incremental $PM_{2.5}$ impact from a major road is approximately 1-2 µg/m³ for the major roadways researchers assessed in their data set.

They also assessed how much pollutant concentrations decrease the further one gets from the road and evaluated the relationship of increments to other factors such as fleet mix, which is the fraction of vehicles that are cars and other light-duty vehicles, versus diesel-powered trucks and buses.

When evaluating NO_2 and $PM_{2.5}$, a key consideration is the fraction of diesel trucks and buses in the fleet, since diesel vehicles contribute disproportionately to those emissions. For analyses involving NO and NO_2 (together referred to as NO_x) or $PM_{2.5}$, EPA and others often consider a

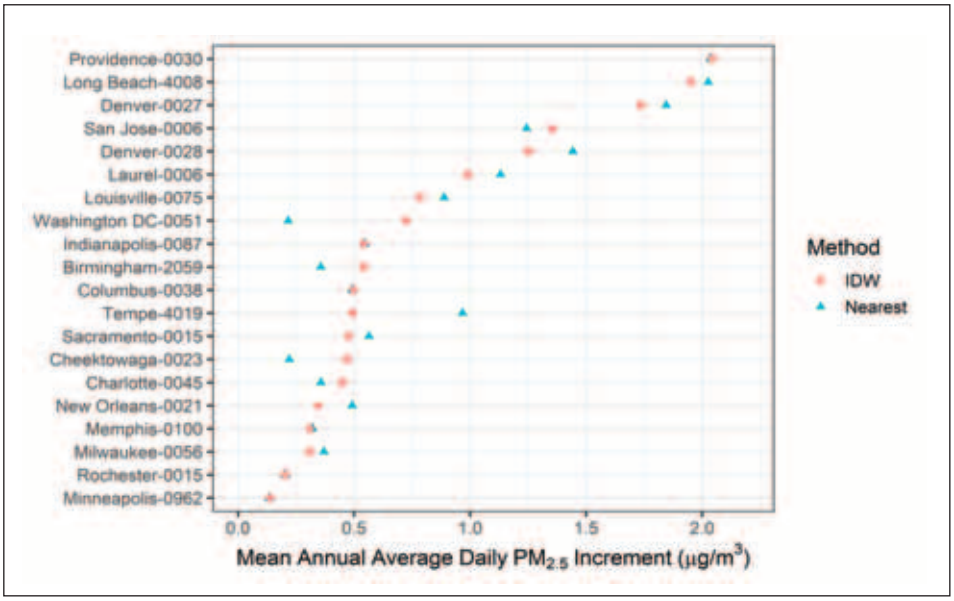

FIGURE 2 **Distributions of annual average $PM_{2.5}$ increments. (Note: IDW = inverse distance weighting method; Nearest = nearest monitor calculation.)**

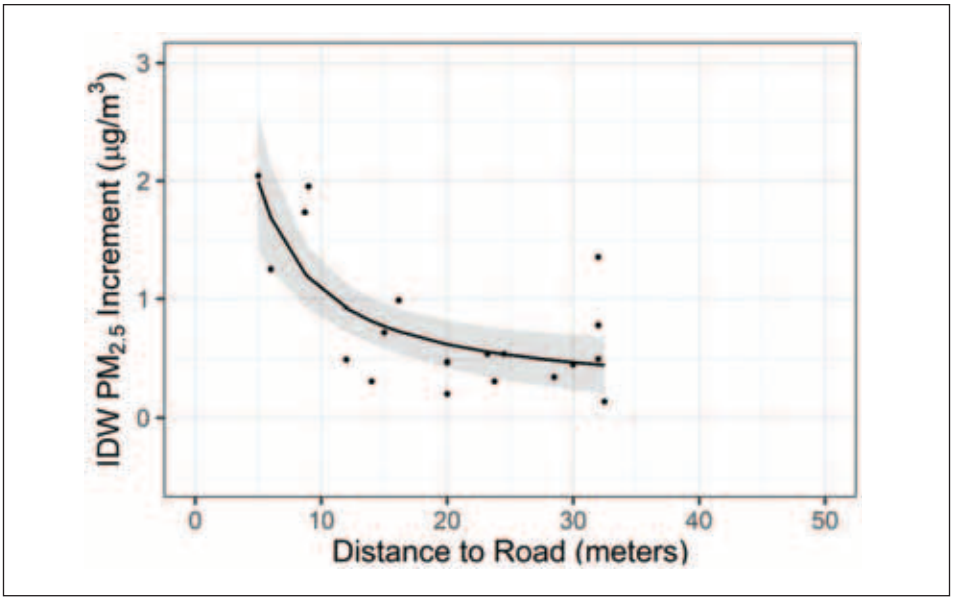

FIGURE 3 Relationship between $PM_{2.5}$ increment (roadway contribution) and distance to road. Regression lines are shown in black, with the range of the standard error of the regression line shown in dark gray. (Source: Mukherjee et al., 2020.)

single heavy-duty diesel vehicle (HDDV) equivalent to about 10 light-duty vehicles (LDVs) in terms of emissions contribution. This allows analysts to convert annual average daily traffic (AADT) counts, which are a mix of cars and trucks, into one pollutant-weighted number, referred to as fleet-equivalent (FE) AADT.

The TPF used FE-AADT to assess relationships between $PM_{2.5}$ and traffic. The research showed, for example, that $PM_{2.5}$ increases by about 0.14 $\mu g/m^3$ for every 100,000 increase in FE-AADT, and that $PM_{2.5}$ increments fell from about 2 $\mu g/m^3$ at 5 meters from the road to 0.5 $\mu g/m^3$ at 30 meters from the road (Figure 3).

Changes on these scales are important because research has shown that death risk from $PM_{2.5}$ exposure rises with increased concentration. Those ages 65 and older, for example, have been shown to experience a 7 percent increased risk of death with every 10 $\mu g/m^3$ increase in annual average $PM_{2.5}$ concentrations.[1]

[1] See the 2019 report from the Health Effects Institute, "Assessing Adverse Health Effects of Long-Term Exposure to Low Levels of Ambient Air Pollution: Phase 1, Synopsis of Research Report 200," found at https://www.healtheffects.org/publication/assessing-adverse-health-effects-long-term-exposure-low-levels-ambient-air-pollution.

Fleet Turnover Projections

Fleet turnover occurs over time as older, higher-polluting vehicles are replaced with newer, lower-polluting vehicles. Table 2 shows projected changes in exhaust emissions for calendar years 2017 to 2040 using an EPA emissions model called MOVES. Data show percent emissions change relative to 2017 for HDDVs, LDVs, and the average vehicle in a fleet composed of 8 percent HDDVs and 92 percent LDVs.

Fleet turnover reduces exhaust emissions in all cases when traffic volumes, fleet mix, and speeds are held constant. For example, exhaust emissions decrease 80 percent from 2017 levels by 2040 for a fleet that is 8 percent HDDVs. Emissions changes for a given roadway will depend on the vehicle fleet and traffic activity over time.

The upper bound increment for near-road sites in 2017 can be combined with the projected change in exhaust emissions (Table 2)—and an assumed fraction of $PM_{2.5}$ that is due to exhaust—to forecast near-road $PM_{2.5}$ increments in the coming decades.

The implications of fleet turnover on $PM_{2.5}$ increments are substantial. In 2017, the upper bound increment from observed annual average $PM_{2.5}$ was 2.0 $\mu g/m^3$, and 1.4 $\mu g/m^3$ for sites 10 meters from the roadway or farther. Assume, as an example, that 40 percent of total roadway-related $PM_{2.5}$ emissions are related to exhaust and 60 percent to nonexhaust emissions such as brake wear, tire wear, and road dust. By 2040, exhaust emissions for an average vehicle in a fleet composed of HDDVs (8 percent) and LDVs (92 percent) are projected to be 20 percent of what they were in 2017 (Table 2).

This means that the $PM_{2.5}$ impact of a highway would fall from about 2.0 $\mu g/m^3$ in 2017 to about 1.4 $\mu g/m^3$ by 2040, assuming constant fleet mix and traffic volumes (FE-AADT) and constant travel speeds across time. For sites 10 meters from a roadway or farther—assuming MOVES national average estimates and constant FE-AADT and speeds—$PM_{2.5}$ roadway increments would fall from about 1.4 $\mu g/m^3$ in 2017 to 1.0 $\mu g/m^3$ by 2040.

Given these projections, the research team also evaluated $PM_{2.5}$ concentration trends using data from the near-road monitoring network. Their findings generally indicated declining concentrations; however, as

TABLE 2 Relative Change in $PM_{2.5}$ Vehicle Exhaust Emissions, 2017–2040

Year	MOVES HDDV	MOVES LDV	MOVES HDDV 8%
2017	100	100	100
2018	87	93	88
2019	75	87	79
2020	66	81	70
2025	34	62	42
2030	18	49	28
2035	13	42	21
2040	12	39	20

NOTE: HDDV = heavy-duty diesel vehicle; LDV = light-duty vehicle.

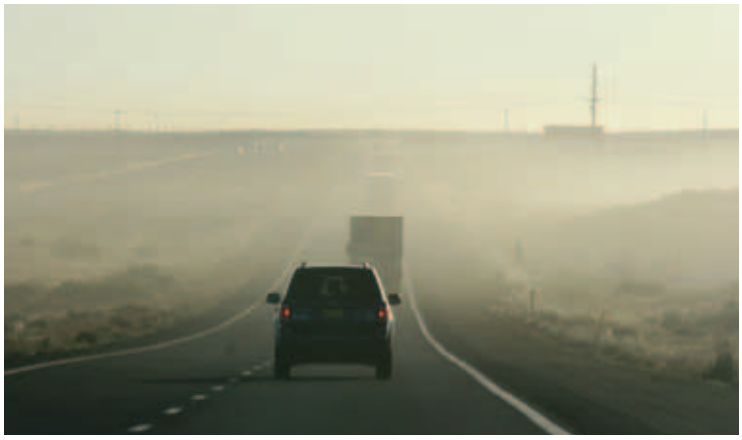

Photo: Quinn Dombrowski, Flickr

Road dust and other elements—brake and tire wear, for example—can comprise 60 percent of roadway-related $PM_{2.5}$ emissions.

of 2019, locations with multiyear data were limited. Measurement trends will become more apparent in the years ahead.

PM Hot Spot Impact Findings

Per EPA mandate, projects identified as projects of local air quality concern (POAQC) must be quantitatively assessed for their PM hot spot impacts. PM hot spot analyses are complex and TPF partners were interested in identifying highway project situations that could be reasonably excluded from such assessments. TPF research used an EPA-defined hypothetical example of a POAQC—set in calendar year 2006, when EPA created the POAQC example—and evaluated how impacts from that project changed over time with fleet turnover.

The EPA hypothetical 2006 project assumed 125,000 AADT and 8 percent diesel truck traffic. The 2006 project example is helpful since emissions from that calendar year and project scale (125,000 AADT at 8 percent diesel trucks) set an EPA-defined benchmark for projects of concern. From this starting point, the TPF estimated emissions for $PM_{2.5}$ and a larger form of PM, particles 10 microns in diameter or less (PM_{10}), for analysis years 2006 to 2035. The point of the work was to illustrate how fleet turnover (newer, cleaner vehicles replacing older, higher-polluting vehicles) affected emissions relative to the EPA benchmark example.

$PM_{2.5}$ emissions based on EPA's emissions model, MOVES, were reduced by 92 percent between 2006 and 2035. Modeling based on a California model, EMFAC, forecasted that $PM_{2.5}$ emissions fell about 70 percent between 2006 and 2035. As exhaust emissions fell, the relative importance of nonexhaust emissions increased (Figure 4).

Because of the emissions-reducing effects of fleet turnover, in later years higher traffic volumes are required to produce the emission levels equivalent to 125,000 AADT in 2006. To examine this effect, researchers held the truck percentage constant at 8 percent and calculated the AADT required in later years to yield emissions equivalent to the 2006 baseline. Using data from EPA's MOVES model, for example, by 2035 it will take more than 1.5 million AADT to produce $PM_{2.5}$ emissions equivalent to those generated by only 125,000 AADT in 2006 (Figure 5).

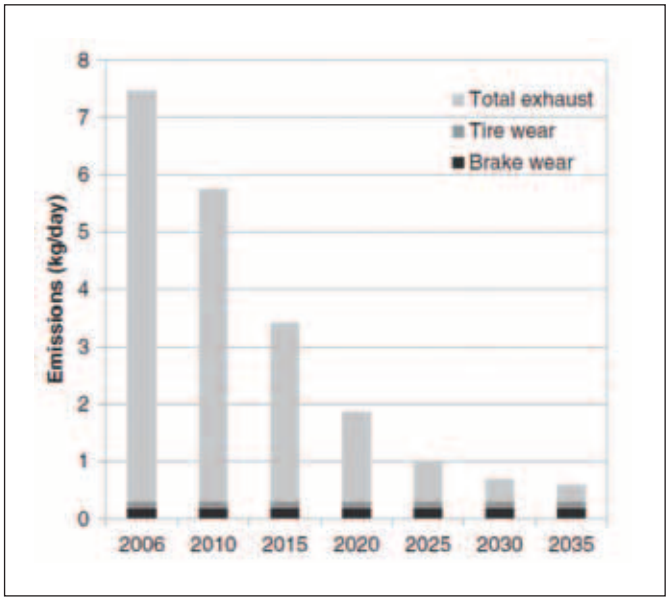

FIGURE 4 $PM_{2.5}$ emissions for a hypothetical freeway project with an AADT of 125,000 vehicles, 8 percent of which are diesel trucks, based on EPA MOVES model. (Source: Reid et al., 2016. Note: AADT = annual average daily traffic.)

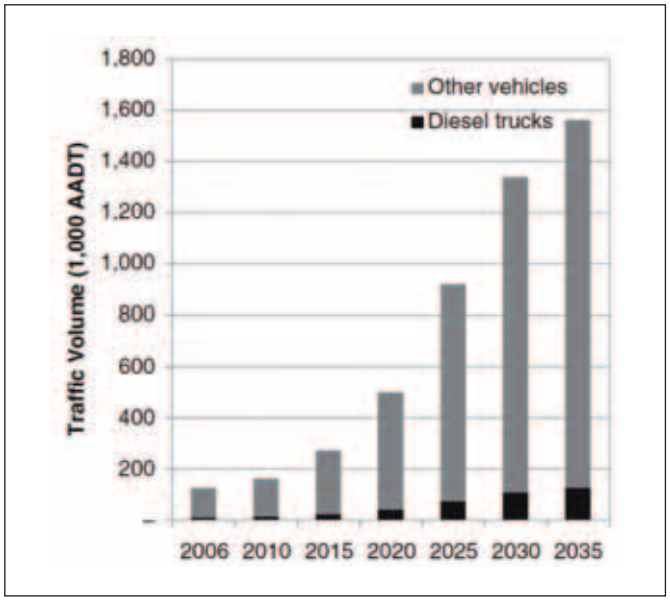

FIGURE 5 Projected traffic volumes needed to produce 2006-equivalent $PM_{2.5}$ emissions, based on EPA MOVES model. (Source: Reid et al., 2016.)

Because transportation projects that may require a hot spot analysis typically add capacity, understanding how capacity and AADT changes affect emissions in future years can help transportation agencies differentiate between projects that may or may not be of concern for air quality.

Comparing Modeled and Measured $PM_{2.5}$

With the 2014 launch of the national near-road air monitoring network, a unique opportunity emerged to compare measured air quality to modeled concentrations. This was of interest to the TPF for two reasons: First, EPA-mandated hot spot analyses rely on modeled outcomes; second, in recent years, EPA encouraged agencies to use an air quality model called AERMOD to assess near-road concentrations. AERMOD is an advanced tool, but compared with other models historically used by transportation agencies, it is complex to run. Therefore, TPF partners were interested in better understanding how AERMOD-modeled outcomes compared to real-world measurements, and how AERMOD results compared to results from simpler-to-run tools used historically.

The TPF evaluated $PM_{2.5}$ concentrations near major freeways in Indianapolis, Indiana, and Providence, Rhode Island, because of their site characteristics and availability of traffic and air quality data. The analyses were built upon bottom-up estimates of temporally and spatially resolved roadway $PM_{2.5}$ emissions based on detailed traffic monitoring data and emission factors specific to the local vehicle fleets. Researchers estimated the difference between $PM_{2.5}$ concentrations at the near-road monitor and at nearby background sites (the measured "increment"), and compared modeled and measured increments.

For Indianapolis, AERMOD was run for 152 analysis days in 2016. The average modeled $PM_{2.5}$ near-road increments for these days were compared to the monitored near-road $PM_{2.5}$ increments. The modeled increment (3.7 μg/m³) was three to four times larger than the measured increments obtained from Federal Reference Method (FRM) or Federal Equivalent Method (FEM) monitoring instruments (1.2 μg/m³ for FRM and 0.9 μg/m³ for FEM). EPA allows the use of either FRM or FEM monitors; FRM measurements usually are more accurate.

AERMOD modeling results for Providence for 2015–2016 were compared with measured increments for 382 analysis days. The AERMOD-based analysis for Providence also significantly overpredicted the average measured near-road $PM_{2.5}$ increment. The average modeled $PM_{2.5}$ increment (8.8 μg/m³) was more than six times, or 530 percent, greater than the average measured increment (1.4 μg/m³).

Photo: Pictr73, Flickr

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Digest of Major Technical Findings

Highlights of major findings from the 5-year TPF program include the following:

1. Near-road concentrations of CO and NO_2 were not problematic when benchmarked against existing NAAQS.
2. Relative to the total number of near-road sites measuring $PM_{2.5}$, a small number of locations exceed the 24-hour or annual $PM_{2.5}$ NAAQS.
3. Near-road $PM_{2.5}$ concentrations are likely trending downward; however, these findings are based on a limited number of sites that operated over the analysis years covered by TPF work. More data are becoming available each year to help establish multiyear trends.
4. Based on 2017 data, for 20 sites across the United States, the upper bound of $PM_{2.5}$ increments was about 2.0 μg/m³. Only three sites had an increment greater than about 1.4 μg/m³; monitors at these three sites were less than 10 meters from the roadway.
5. The work provides a better understanding of the likely incremental increase in pollutant concentrations coming from the roadway. Over time, because of anticipated fleet turnover, the forecasted $PM_{2.5}$ increment will decrease for a given volume of traffic with constant speeds and fleet mix. TPF findings can help transportation agencies differentiate between projects that may or may not be of concern for air quality.
6. There can be substantial differences between measured and modeled near-road $PM_{2.5}$ concentrations. For the case studies presented here, modeled concentrations substantially overpredicted measured values.

Areas of Future Research

Future work could further examine the following topics:

1. The relative contribution of exhaust and non-exhaust $PM_{2.5}$ emissions.
2. Modeled and measured near-road concentrations across different geographic settings, roadway types and configurations, and at more sites over multiyear periods.
3. Modeling chain biases contributing to differences between measured and modeled concentrations.
4. Quantitative estimates of the effects of near-road barriers and roadway grade on near-road pollutant concentrations, to derive insights that will help mitigate concentrations considered problematic in some near-road settings.

Acknowledgments

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Also, appreciation goes to the STI Publications team: Jana Schwartz, Mary Jo Teplitz, and Bryant West. Findings included here are excerpted from prior TPF work.

Further Reading

The following peer-reviewed articles document findings from the Near-Road Air Quality TPF:

Craig, K.J., L. M. Baringer, S.-Y. Chang, M. C. McCarthy, S. Bai et al. Modeled and Measured Near-Road $PM_{2.5}$ Concentrations: Indianapolis and Providence Cases. *Atmospheric Environment*, Vol. 240, Nov. 2020, p. 117775. doi.org/10.1016/j.atmosenv.2020.117775.

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