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Project Title

Impacts of Wildfire Smoke and Other Area-Wide Air Pollution on Multimodal Traffic Volumes

University

Utah State University

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Research Needs

Although research about the effects of the transportation system on air quality and air pollution is plentiful (e.g., Caiazzo et al., 2013), research emphasizing the reverse link—i.e., how measurements of air pollution impact multimodal traffic volumes and other aggregate outcomes of individuals' travel behaviors and transportation choices—is minimal. In many parts of the world, including in the western and central US, air pollution can frequently reach unhealthy or hazardous levels, affecting both urban and rural downwind communities and negatively impacting public health, out-of-home and outdoor activities, recreation, and tourism. In addition to pollutants like fine particulate matter and ground-level ozone from various sources (e.g., transportation, manufacturing, agriculture), smoke from wildfires in the US and Canada is increasingly the cause of extreme air pollution in these areas (Burke et al., 2020). In order to improve public health as well as prepare for and manage responses to such extreme events, it is important to know how people's travel behaviors are affected by wildfire smoke and other air pollution.

Previous research has documented how adverse weather conditions—such as cold or very hot temperatures, snow and rain, and strong winds—affect people's travel behaviors and mode choices, resulting in aggregate changes in traffic volumes for various modes (e.g., Zhao et al., 2019; Runa & Singleton, 2021). Since many forms of air pollution (especially wildfire smoke) are similarly seen and sensed (through vision, smell, and breath), we expect that adverse air quality also affects travel behaviors and traffic volumes, although the manner of these effects may differ. Although some studies have looked at the transportation behavior effects of micro-scale street-level air pollution concentrations on, for example, bicycle route choice (e.g., Anowar et al., 2017), there is a need to study the impacts of area-wide air pollution events such as wildfire smoke, dust storms, and wintertime inversions on the use of multiple modes of transportation.

First, there is a need to look at these air pollution impacts across multiple transportation modes. Air pollution exposure has been found to vary by mode. Across several US studies (Chaney et al., 2017; Morabia et al., 2009; Good et al., 2016), people walking or bicycling had higher exposures to fine particulate matter, compared to automobile, transit, and other modes. As a result, the impacts of adverse air quality conditions are likely to influence these active transportation modes more than other encapsulated modes (Ma et al., 2017). In fact, higher concentrations of air pollutants have been found to be associated with reduced outdoor physical activity (An et al., 2019), although studies mostly relied upon samples of self-reported behavioral data. Such insights could inform infrastructure management and operational responses.

Furthermore, travel behavior responses to air pollution may include mode shifts (Li & Kamargianni, 2017), such as switching from walking or bicycling to public transit or driving. A focus on just one mode of transportation—driving (Tribby et al., 2013), bicycle/pedestrian counts (Doubleday et al., 2021), or public transit ridership (Welch et al., 2005; Wu & Liao, 2020)—may obscure policy-relevant differences and shifts between modes. Despite some evidence that the physical activity benefits of active travel outweigh the damage caused by air pollution exposure (Tainio et al., 2016), travelers facing outdoor air pollution are presented with a potential personal behavioral conflict between risk aversion (I should reduce my exposure by not walking/bicycling) and altruism (I should reduce pollution by not driving) (Noonan, 2014). Analyses utilizing multimodal data can be designed to identify modal substitution patterns that could shed light on policy implications—e.g., voluntary (soft) vs. mandatory (hard) policies—aimed at reducing air pollution emissions and exposures.

Second, there is a need to consider how the impacts of area-wide air pollution on multimodal traffic volumes may vary in different temporal and spatial contexts. As with weather (e.g., Zhao et al., 2019), aggregate travel behavioral responses to air pollution may vary by day-of-the-week or season. For example, walking and bicycling are less commonly used during the coldest or wettest parts of winter or the hottest days of summer (e.g., Runa & Singleton, 2021), so the impacts of air pollution on those modes may be attenuated at those times. Geospatial variations in the linkages between air pollution and traffic volumes may be even more substantial and yield more actionable insights. For example, Son and Mobasheri (2017) reported that non-commuting cycling activities were more pronounced at city outskirts than the center, and that recreational cycling was associated with lower air pollution levels than those commuting. Tribby et al. (2013) found that small decreases in motor vehicle volumes in a city center on days with air quality alerts were offset by larger volume increases in suburban areas near recreation. Investigating how the transportation impacts of air pollution vary across neighborhoods with different degrees of urbanization, access to multimodal transportation systems (e.g., highway, rail, bus, shared mobility), and levels of poverty or disadvantage could provide insights into potential policy strategies to allow everyone the opportunity to avoid the health risks of exposure to wildfire smoke and other area-wide air pollution.

Research Objectives

The overarching goal of this research project is to understand how wildfire smoke and other area-wide air pollution affect traveler behaviors in Utah. We achieve this aim through three specific objectives:

- Quantify the impacts of wildfire smoke and other area-wide air pollution on multimodal traffic volumes.
- Identify aggregate-level travel behavior changes associated with wildfire smoke and other area-wide air pollution.
- Characterize and explain geospatial variations in how wildfire smoke and other area-wide air pollution affect multimodal travel.

First, we quantify how much and for how long air pollution (e.g., as a result of wildfire smoke) impacts multimodal traffic volumes (motor vehicle volumes, transit ridership, and bicycle/pedestrian counts) after controlling for other factors, such as weather. We expect a moderate change in traffic volumes (less than 5%) on and immediately after days when the air pollution is "unhealthy" or worse, although we anticipate greater changes (and reductions) for non-motorized modes.

Second, we identify how air pollution (including wildfire smoke) results in aggregate-level travel behavior changes, such as mode share adjustments, shifts of trips to later days, or changes in vehicle miles traveled. For example, we anticipate that summertime wildfire smoke may result in overall trip reductions but also mode shifts from active to motorized modes.

Third, we characterize spatial variations in how wildfire smoke and other air pollution impacts multimodal traffic volumes and aggregate travel behavior changes. Locational factors include elevation, urban vs. rural, the built and natural environments, and socio-economic status of a neighborhood. For example, during wintertime inversions, we expect an increase in motor vehicle traffic volumes in higher-elevation recreational areas and at the urban periphery.

Research Methods

Data: We will assemble multi-year daily data on multimodal traffic volumes, air quality, weather, and locations from a variety of sources. Data on motor vehicle traffic volumes will be assembled from a variety of Utah Department of Transportation sources, potentially including: more than 150 continuous counting stations located on Utah highways; hundreds of volume sensors on Utah freeways, archived in the Performance Measurement System (PeMS); traffic detectors at over 1,500 signalized intersections in Utah, accessed through the Archived Traffic Signal Performance Measures (ATSPM) system; or relative volumes or origins/destinations from vehicle probe data (Iteris ClearGuide) or Bluetooth sensors (Blyncsy) for most Utah roadways. Transit ridership or boarding/alighting data may be available from the Utah Transit Authority and other Utah transit agencies. Data sources for traffic counts of people walking and bicycling may include: dozens of permanent trail counters in several Utah counties; Strava node/edge data for Utah; and pedestrian crossing volumes at over 1,500 Utah traffic signals, estimated from pedestrian push-button data (Singleton & Runa, 2021). Air quality data (about fine particulate matter and ground-level ozone) will come from air quality sensors throughout Utah, accessed through the Environmental Protection Agency's air quality data portal. Weather data (temperature, precipitation, wind, humidity, etc.) will come from weather stations throughout Utah, accessed through the National Oceanic and Atmospheric Administration's National Centers for Environmental Information. Geospatial and socio-demographic information about locations with traffic volumes will be obtained from a variety of sources, including the US Census Bureau, the Utah Automated Geographic Reference Center, and the Utah Department of Transportation.

Analysis: We will consider a variety of big data analysis methods for analyzing these data and achieving the study's research objectives. Our first goal is to determine associations between air pollution levels and multimodal traffic volumes, while controlling for other causes of temporal variations in traffic volumes (weather, weekdays, holidays, special events, etc.) and long-term trends. Generally, we anticipate accomplishing this through simultaneous estimation of multiple time-series regression models, such as autoregressive integrated moving average (ARIMA) models. Then, we will capture any aggregate mode shifting by linking changes in one mode to changes in another mode within the same area (e.g., through correlated error terms), as well as to quantify any sustained effect over several days (e.g., through time lags).

Another aim is to characterize spatial variations in how air pollution affects traffic volumes through associations with locational characteristics, so we may also aggregate data by location. The structured nature of the data (daily traffic volumes nested within locations; i.e., each location has multiple daily traffic values) suggests a multilevel modeling approach. Also, spatial autocorrelation (i.e., the similarity in traffic volumes among locations that are close together) can be addressed through an eigenvector spatial filtered multilevel (ESF-ML) model (Griffith, 2005). As alternatives, machine learning methods including random forest and gradient boosting will be also considered and compared based on their explanatory power.

Expected Outcomes

This research is expected to produce quantified knowledge about the magnitude, longevity, interconnectivity, and spatial variation in the impacts of wildfire smoke and other area-wide air pollution on multimodal traffic volumes. Although we expect that air pollution may have only a modest effect on traffic volumes overall, we do anticipate identifying some modal shifting and larger impacts in specific types of areas or neighborhoods. This information could be used by transportation agencies in Utah and the western/central US to manage infrastructure operations and to prepare for and mitigate any traffic impacts and mode shifts due to smoke from wildfires, wintertime inversions, and other area-wide pollution events. The impacts we quantify can also be used in future research and practice, to estimate the exposure of various road users to air pollution and any corresponding human health impacts. This project is also expected to develop several open-source data processing and analysis scripts that will be shared with the research community.

Relevance to Strategic Goals

USDOT Strategic Goal: Environmental Sustainability. The transportation sector is one of the leading contributors to the emission of greenhouse gases and other air pollutants that negatively impact human health, well-being, and the economy. Understanding how travelers, in aggregate, respond when faced with elevated levels of area-wide air pollution can inform policies designed to reduce emissions or mitigate the harmful effects of poor air quality.

Educational Benefits

Two Ph.D. students will be involved in this project as graduate research assistants. Both students will gain general project management, communication, and data management skills, as well as discipline-specific skills such as travel behavior data analysis, spatial econometrics, and machine learning. One Ph.D. student will focus on assembling and managing the various data sources, while the other Ph.D. student will focus on conducting the statistical and machine learning data analyses. Both students will take the lead on many of the research project's major tasks, including writing and presenting results.

The PI Singleton teaches undergraduate/graduate-level courses on transportation data analysis and transportation planning. The co-PI Park also teaches undergraduate/graduate-level courses on GIS, 3D visualization, and research methods in environmental planning and design. Data, analyses, and findings from this project will be used as examples in those courses.

Technology Transfer

The findings of this research project will be disseminated to other researchers, professionals, and practitioners in several ways. We will share results with the research and professional community through presentations at local, national, and/or international conferences such as meetings of the Utah Department of Transportation, the Institute of Transportation Engineers, and the Transportation Research Board. In addition to the project report, we plan to prepare two manuscripts and submit them for publication in transportation and planning journals. The final report will be sent to transportation staff colleagues at state and local transportation agencies, and the presentations and articles will also be shared on the PI Singleton's personal research website (https://engineering.usu.edu/cee/research/labs/patrick-singleton/index). Data management and analysis scripts will be shared with the research community on the PI Singleton's personal GitHub page (https://github.com/singletonpa).

Work Plan

1. Review literature on how wildfire smoke and other area-wide air pollution affect traveler behaviors and multimodal traffic volumes.

This task involves reviewing existing published scientific knowledge about the effects of air pollution on travel behaviors and traffic volumes. The review will include a systematic search of research databases for journal articles and academic reports on these topics, with a focus on area-wide air pollution such as due to wildfire smoke. We will also review data sources and analytical methods of multimodal traffic volumes, air quality, and locations in the literature. A critical synthesis of the literature will be produced, including summaries of findings, data sources, and analysis methods. This task will be completed approximately 4 months after the project starts.

2. Assemble data on multimodal traffic volumes, air quality, weather, and geospatial characteristics of locations.

Concurrently, this task involves assembling data to be used in the later analyses. Several years (potentially including 2020) of daily data on multimodal traffic volumes, air quality, weather, and locations will be obtained from a variety of sources. (See Research Methods section above for more details.) This task will be completed approximately 5 months after the project starts.

3. Perform data fusion on the assembled datasets.

This task involves merging these disparate data sources into one consistent dataset to use in the analyses. The various data assembled in the previous task may be in different formats, cover different time intervals, and be for different locations. This task will fuse data together based on common temporal and spatial information. For example, some spatial interpolation may be necessary to join air quality and weather data to locations with multimodal traffic volume data. Locational characteristics (geospatial and socio-demographic) will be calculated for the neighborhood surrounding each traffic volume location. Missing or potentially erroneous data may be cleaned, imputed, or removed. This task will be completed approximately 7 months after the project starts.

4. Refine data analysis methods for a small area and short timeframe.

Before trying to analyze a large region and a long timeframe, this task will develop and refine our study's analysis methods for a smaller area and shorter timeframe. We anticipate focusing on a small portion of one of Utah's urban areas (e.g., an area with a population of around 50,000) and no more than one year's worth of data. The specific study area and timeframe will depend upon data availability. A variety of analysis methods may be employed or tested, including time-series, spatial/multilevel, or machine learning approaches. (See Research Methods section above for more details.) This task will be completed approximately 10 months after the project starts.

5. Apply data analysis methods to a larger region and longer timeframe.

Once the technical details of the analysis methods are worked out for a small area and short timeframe, this task will apply those methods to a larger region and a longer timeframe. We anticipate analyzing at least one of the six most populous Utah counties (Salt Lake, Utah, Davis, Weber, Washington, and Cache, all with populations greater than 100,000) and at least two years of daily data. The final decision around the study area and timeframe will depend upon data availability (from Task #3), model efficiency (from Task #4), and computational capacity. This task will be completed approximately 13 months after the project starts.

6. Prepare report, presentations, and papers.

To aid in technology transfer, a final report will be prepared, as well as conference presentations and journal publications. This task will be completed approximately 14 months after the project starts.

Project Cost

Total Project Costs:	$180,000
MPC Funds Requested:	$ 90,000
Matching Funds:	$ 90,000

Source of Matching Funds: Utah Department of Transportation; $65,000; financial support
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