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Leveraging V2X data insights on air quality to unlock funding opportunities

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Abstract

Vehicle-To-Everything (V2X) data is a key input to unlocking funding that is critical for connected vehicle program development, execution, and maintenance. Access to financial resources is vital for transportation and roadway agencies to make a lasting impact on our environment. V2X technology has been flagged as a major contender to both measure and impact air quality due to its ability to produce quantifiable data and thus insights on air quality. With the ever-growing number of connected vehicles that are on our roads, it is essential to explore how these data sources can help unlock new funding opportunities to lead to improved air quality. These alternative data sources can provide insights into emerging trends, the efficacy of the technology, and innovative methods for air quality control strategies. The purpose of this technical paper is to demonstrate the rigor of V2X data and share a method to quantify air quality impacts.

Keywords: V2X EFFICACY, AIR QUALITY

Introduction

In recent years, conversations abound on global air quality, with an emphasis on mitigation and control efforts to reduce current day air pollution. Previously, this may have been confined to industry practitioners and policy makers (at local, national, and international levels), but now it is common to observe everyday conversations between citizens who reside in the very same communities targeted for air quality improvements. The private sector has also become involved in developing innovative ways to reduce air quality[1]. Much progress has been achieved over the years, ranging from educating the public on what air quality is to realizing substantive improvements to pollution levels, but more is possible. Specifically, there is significant promise in leveraging new and innovative transportation technologies to monitor and reduce harmful emissions from roadway operations, as the transportation sector contributes largely to the quality of air we breathe. Specifically, in 2020, it produced 7.29 tonnes of carbon dioxide-equivalents, globally (Ritchie, Rosado, & Roser, 2020).

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[1] Google is researching ways to use driving trends sourced from Google Maps to enhance traffic signal coordination in ways that can reduce emissions (Matias, 2023).

In this paper, we present one such transportation technology, vehicle-to-everything (V2X) communications, that can deliver on air quality reduction efforts. Before proceeding, we take a moment to define a few topics. What do we mean by "air quality?" Relatedly, how is it measured, what concerns exist about its current state, and what actions are being taken to alleviate these concerns? We follow this discussion with a proposal for how V2X can serve as an air pollution reduction strategy, highlighting a case study in the United States (US) with the Utah Department of Transportation (UDOT). We conclude with guidance on how others can adopt this work by tapping into financial resources that make this effort possible.

Air quality: Current state and mitigation strategies using V2X

The World Health Organization defines air quality as the amount of pollution in the air that we breathe, and it is the largest risk posed today to human health from environmental factors (WHO, 2022). Air pollution is largely caused by greenhouse gas emissions generated by human activity, especially as it pertains to activities within commercial and residential operations, agriculture, and electricity production. The economic sector contributing the largest amount of greenhouse gas emissions in the US is the transportation sector (28%) by way of gasoline and diesel consumption from highway and passenger internal combustion engine (ICE) vehicles operating on the roadway (EPA, 2023a). All ICE vehicles emit carbon dioxide (CO_2), a critical gas in air quality values, which notably represents the bulk of all gas emissions under the greenhouse gas category[2]. Recent trends show a global increase in CO_2 emissions, up 51% from 1990 to 2015 (WRI, 2022).

In response to historical trends showing a reason for concern, mitigation and/or maintenance efforts have increased in recent years. The US, a top emitter of CO_2 per capita, has pledged an effort to mitigate their emissions as a part of the United Nation's Net Zero Coalition effort (United Nations, 2023; WRI, 2022). Some of their control strategies for pollution mitigation focus on activities stemming from the transportation sector, such as encouraging efficient driving practices[3], providing guidance on routine vehicle maintenance, and urging vehicle fuel conversion to renewable energies[4] to name a few. The Environmental Protection Agency (EPA) has also encouraged reducing emissions from vehicles on the roadways through innovative transportation projects (EPA, 2023a). V2X technology is one viable approach that meets this recommendation.

V2X is an advanced communication system that allows vehicles to communicate with other vehicles (V2V), infrastructure (V2I), pedestrians (V2P), and the network (V2N). V2X technology can play a critical role in improving and enhancing air quality as well as the safety and mobility of our roads through sharing real-time data and warnings across these different modalities of V2X. This allows drivers to receive pertinent information

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[2] Other greenhouse gasses include methane (CH_4), nitrous oxide (N_2O), and fluorinated gasses (e.g., hydrofluorocarbons [HFC]), but they represent a fraction of all emissions from transportation activities.

[3] International programs such as SmartWay (United States), Fleet Smart (Canada), and Transporte Limpio (Mexico) collaborate to improve freight operations in North America.

[4] In the United States, the Clean Air Act (CAA) enacted in 1963 focuses on domestic strategies to control and reduce air pollution nationwide through on-road vehicle regulation that limits, for example, evaporative emissions.

about possible road hazards and conditions and helps to improve drivers' situational awareness to avoid accidents. V2X technology can also be used to provide eligible vehicles with permissions to traverse traffic intersections more expediently (via connected intersection preferential treatment [CIPT]), which may improve roadway mobility by reducing time spent idling. Reduced idling can lead to fewer emissions and improved air quality by way of reduced fuel consumption.

Case study: Utah Department of Transportation, Utah, United States

Salt Lake City, Utah ranks 10th in the US for worst ozone pollution and 19th for worst short term particle pollution (American Lung Association, 2023). Given this, air quality is a concern for many Utahans. UDOT has deployed a V2X technology ecosystem that may safeguard and improve factors contributing to the state's air quality ranking. Herein we share details about this project, with a focus on how data made available through this technology enables the measurement of core vehicle activities that directly influence air pollution levels.

Deployment region

Panasonic North America and UDOT partnered to further a real-world deployment of V2X technology in and around Orem, Utah ("the Orem V2X Enclave"), situated to the south of Salt Lake City, Utah. The team selected this geographic region for several reasons, three of which are 1) it is the site of a heavily utilized transit bus route where requests for transit signal priority (TSP) could be enabled, 2) it includes common snow plow routes where requests for traffic signal preemption may be needed during adverse weather conditions, and 3) it provides an opportunity to serve emergency vehicles (fire trucks, ambulances) with traffic signal preemption during their journey to an incident site. Enabling TSP or preemption (CIPT) in this footprint for these vehicle types serves as a mechanism to indirectly impact the environment via lower emissions due to improved traffic flow.

Field work for hardware installation, verification, and validation testing lasted approximately one year, finalizing in early 2023. Upon completion, this deployment included approximately 130 roadside units (RSU) as well as 150 vehicles equipped with onboard units (OBU). RSU installation sites are situated within an approximate 11-square-mile area of Orem City proper and extends to surrounding corridors connecting the neighboring cities of Provo, Utah and Lehi, Utah. The OBUs were installed in a variety of public works vehicles, often medium- to heavy-duty, which frequently operate in this area. They include transit buses, snowplows, and emergency vehicles (fire trucks, ambulances). Figure 1 depicts the geographical reach of the RSU deployment and the proximity of the Orem V2X Enclave (represented by blue icons) to the CIPT-specific deployment locations (represented by red icons).

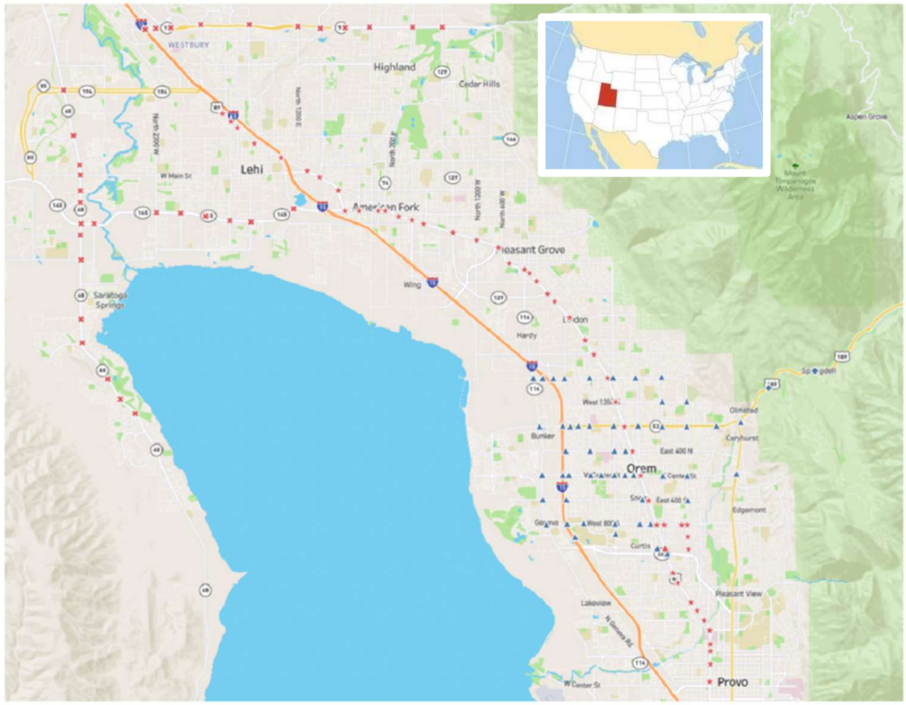

Figure 1 - Illustration of RSU deployment in the Orem V2X Enclave

Objective

V2X technology, particularly in places like Utah, affords industry technicians and practitioners alike a new and unique manner to track factors that impact air pollution values in the communities in which they work and reside. The vehicle activities we discuss in this paper come from a common, everyday roadway operation – vehicle idling. It is the very nature of V2X that allows us to identify in (near) real-time when and where a vehicle idling event occurs as well as the duration of this event. Unlocking the identification and measurement of this activity just scratches the surface for the value V2X data can provide. Knowing when, where, and the duration of these vehicle events opens the door for deeper analytics on related fuel consumption and emissions (such as CO_2) stemming from these idling events that directly influence air pollution levels (Massachusetts Government, 2023). With V2X technology a reality in Utah, we can objectively measure what is happening on the roadways and implement control strategies that would reduce vehicle idling events (via improved traffic flow). The objectives of this case study are to reveal:

1. Air quality trends as it relates to vehicle idling, fuel consumption, and emissions over time.
2. CIPT's ability to reduce fleet vehicle idling, fuel consumption, and thus improve air quality.

The data

V2X technology can receive data from vehicles up to 10Hz, and during the deployment we received over 40GB of data per month. Many of the data elements provide information about vehicle operations, intersection geometry, traffic signal operations, and vehicle requests for priority treatment[5], all of which are critical to measuring roadway inputs to air quality in this case study. The raw data is not only voluminous, but it also requires significant preparation before it can be analyzed. For example, we often receive the same BSM from multiple RSUs that are in range of the vehicle. Therefore, to make this data more usable, we deduplicated BSMs received from multiple RSUs and began data aggregation to create vehicle idle events (and the duration of these events) specifically at intersections within the MAP. For this case study, we analyzed data received during the period of October 2022 to the end of July 2023.

Vehicle events contributing to air quality

Because of the state of raw V2X data, we must manipulate the data elements through logic to arrive at specific events, such as identifying when the vehicle is in a parked state or stopped at an intersection for a red light. For this analysis, we created one core event from the raw data: a vehicle idling at an intersection. An instance of a vehicle idling at an intersection is flagged in the BSMs when four conditions are met simultaneously—the V2X-equipped vehicle has its ignition turned on, the vehicle transmission state is in "Drive" to enable forward movement, the vehicle is stationary as indicated by its speed being 0 miles per hour (mph), and the vehicle's location is within the geographic extents of the MAP. If these four conditions were present, we flagged that record as an instance of vehicle idling. Next, we aggregated all instances of vehicle idling in an intersection to obtain the total duration of an idle event per vehicle since it is often likely that one vehicle could produce multiple idle instances in the ingress lane while queuing at an intersection. This process allows us to calculate the average duration of a total idle event for all vehicles that move through an intersection. It is important to note that typically vehicle BSMs are anonymous for data privacy, but since this case study is on fleet-owned vehicles requesting preferential treatment at an intersection, there is an assigned vehicle identifier allowing for this aggregation method.

After determining the duration of an idle event, we calculated a fuel consumption value and a related emissions factor for each of these events. For fuel consumption, we used the duration of the idle event (in seconds) and applied a standard fuel usage value from the Department of Energy (DOE)[6] that can vary based on the fuel type, vehicle type, and vehicle load. We then converted the fuel consumption value into a CO_2 emissions factor based on a standard conversion from the EPA[7] that is based on the fuel type of the vehicle. These metrics allow us to uncover both the vehicle idling, fuel, and emissions trends.

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[5] These V2X data elements are standardized to the SAE J2735 format. Specifically, vehicle operations come from basic safety messages (BSM), intersection geometry comes from the MAP, traffic signal operations come from signal phase and timing messages (SPaT), and vehicle requests for priority treatment at the intersection come from signal request messages (SRM) and signal status messages (SSM).

[6] Calculated using the Argonne National Laboratory's Idling Reduction Fuel Worksheet (DOE, 2023).

[7] Tailpipe emissions (CO_2) burned per gallon of fuel is estimated using the Office of Transportation and Air Quality's report titled "Tailpipe Greenhouse Gas Emissions from a Typical Passenger Vehicle" (EPA, 2023b). Values are estimates only, as they are derived for passenger vehicles instead of non-passenger vehicles.

Findings

After flagging all vehicle idle events in Utah intersections, we began to analyze the average duration of these events per intersection on a given date. Figure 2 illustrates daily variance in the number of idle events (orange bar graph) and the duration of these idle events (blue line graph) from October 2022 through the end of July 2023. The data revealed that the number of events steadily increased during the deployment process, with a dip around the new year, likely due to the holidays. After the date when all equipped fleet vehicles were considered online (January 17, 2023), the number of idle events stabilized with a new trend appearing that showed variability in event frequency between weekdays and the weekend. More details on variance by key segments are discussed later (i.e., day of the week and time of day). The data also showed that the duration of idle events varied initially, but after all equipped fleet vehicles were online idle events stabilized around the mean duration of 26.56 seconds.

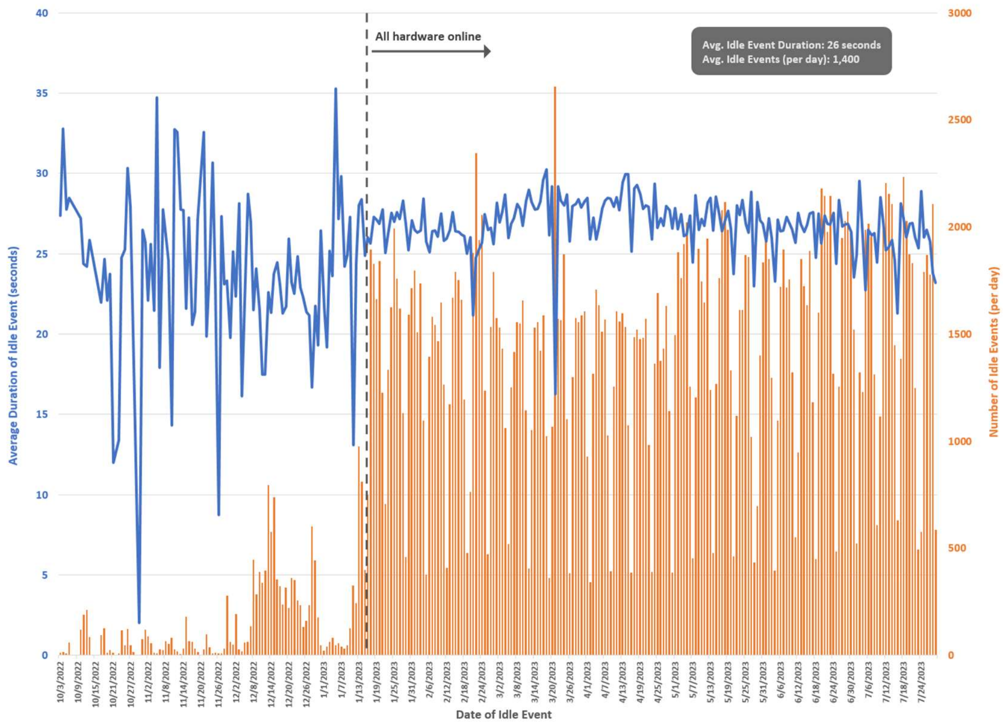

Figure 2 - Number and average idle duration (seconds) by day

When it comes to the various segments of the data (i.e., day of the week and time of day), we found no difference in the average duration of an idle event between weekend and weekdays[8], but did find a difference in the number of idle events where weekdays had a higher number of idle events (n= 84,829, 86.58%) than weekends (n= 14,290, 14.42%). This might be the case because many of the V2X-equipped vehicles are municipal fleet vehicles that are used less often over the weekend or are transit buses with reduced service frequency over the

[8] t(99,119)= 0.001, $p > 0.05$

weekend. We also found that during peak hours there is a higher overall average idle duration[9]. Interestingly, the number of idle events was lower during peak hours (n= 40,380, 40.74%) compared to off-peak hours (n= 58,730, 59.26%), suggesting that although there are fewer stops during peak hours when a vehicle does come to a stop, it tends to idle for a longer duration.

Next, we calculated the amount of fuel consumed during each observed vehicle idle event. Figure 3 juxtaposes the average duration of idle events (in blue) with the average fuel consumed (in green) by day, and this shows that that fuel consumption follows the pattern of idle duration.

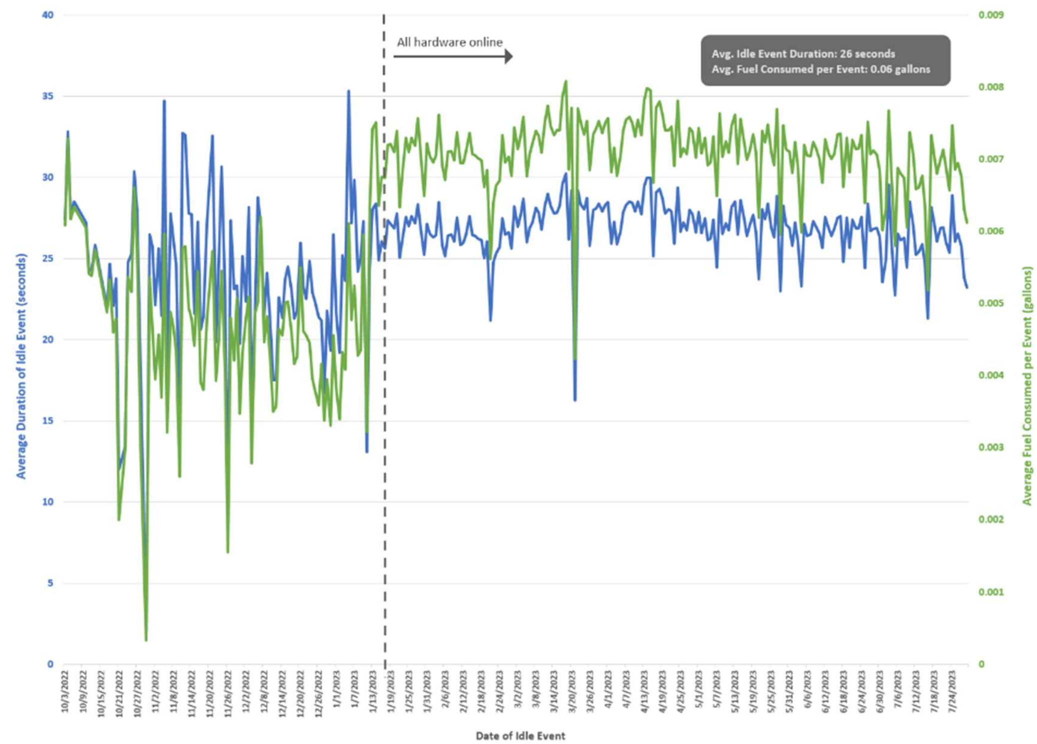

Figure 3 - Average idle duration (in seconds) and average fuel consumed per day

This fuel consumption value can also be translated into a CO_2 emissions factor. During an average 26-second idle event, 0.06 kg of CO_2 are emitted. Over the course of a day, with roughly 1,400 idle events, that equals 84 kg of CO_2 emitted per day. If we were to reduce the average idle event by a modest 15% (i.e., 4 seconds), that would lower CO_2 emissions by 13 kg per day. If this were to continue over the course of a year that could result in a reduction of 4,599 kg of CO_2. That equates to 76 tree seedlings grown for 10 years or switching 174 incandescent light bulbs to LEDs.

Next steps

The results presented here are just the first step in a multi-stage analysis. This solely uncovers trends in V2X

[9] Peak hours are between 6-9am and 4-7pm; t(99,119)= 2.51, $p < 0.05$

data related to vehicle idling, fuel usage associated with this idling, and resulting emissions. Next steps are to uncover if and how much CIPT improves these factors. A key variable to consider when conducting this analysis is to understand if a vehicle's request for TSP or preemption was granted. This is important because CIPT may enable an expedited intersection traversal that reduces vehicle idling. To determine if a request was granted or not granted, we plan to use Signal Phase and Timing (SPaT) data[10] to identify deviations to a green (i.e., green extension) or red (i.e., red truncation) phase in the cycle. Additionally, SPaT data has a field that indicates whether preemption or TSP is active and may allow us to know with more certainty whether these requests were granted. This would allow us to measure how these critical V2X use cases (i.e., enabling signal priority or preemption for large, contributing fleets) could reduce pollution through reducing vehicle idling, which could result in more stable traffic flow. Future analyses will also begin to examine how other vehicle activities like acceleration and deceleration contribute CO_2 emissions. We believe providing a holistic view of vehicle operations along a trip (in and outside of the traffic intersection) is possible with V2X data. Estimating vehicle idling is merely a starting point, perhaps a proof of concept, for being able to measure emission outputs (and potential reduction through gained travel efficiencies) more precisely.

How can you get involved?

There is real potential for other entities to mobilize toward innovative approaches that mitigate emissions stemming from roadway activity, and funding is available. UDOT's connected vehicle program is made possible, in part, through grant funds administered by the US government. Although the funding grant for UDOT's project is more broadly related to roadway improvements, not just environmental improvements, federal assistance from the Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) is a key financial resource that has enabled overall efforts as well as the potential tangential impacts on air quality[11].

If seeking ways to replicate such deployments in your jurisdictions through similar mechanisms, there are a wealth of untapped financial opportunities to consider that are targeted at the transportation sector worldwide. The State of Global Air Quality Funding 2023 provides a comprehensive report on current global funding opportunities, with donors of outdoor air quality projects reaching a value of $2.3 billion (Clean Air Fund, 2023). A smaller subset of this funding is dedicated to opportunities in the transportation sector. The US federal government has also made available financial aid through their Federal Highway Administration's Congestion Mitigation and Air Quality Improvement program (CMAQ). The intent of this grant funding opportunity is to facilitate the reduction of emissions stemming from mobile sources to include transit improvements as well as the implementation of emerging technologies (FHWA, 2022b; FHWA, 2023). V2X deployments should be

[10] SPaT messages contain information about each traffic signal phase and the associated time for each phase. This data source is valuable in this context, as it is a standardized message received as part of this and similar V2X deployments. No 3rd-party data source is required.

[11] This grant targeted applicants from state, local, or political subdivisions of transit agencies and metropolitan planning organizations to name a few who engaged in activities that met eligibility criteria, such as vehicle-to-vehicle, vehicle-to-infrastructure communications (FHWA, 2016). Note that the Bipartisan Infrastructure Law amended this grant program, and it is now referred to by the Federal Highway Administration as the Advanced Transportation Technologies and Innovation (ATTAIN) program (FHWA, 2022a).

considered as fitting squarely within these eligibility requirements. There is also a benefit to examining long-term, self-funding opportunities generated by averting routine operating expenses (such as wasted fuel). For example, the analysis of focus in this paper estimates fuel consumption during a vehicle idle event to arrive at an emissions factor. We believe that as our study advances, we will find V2X applications, such as CIPT, can produce cost-savings in other realms (i.e., by reducing the amount of fuel a vehicle expends due to more stable mobility during its trip)[12]. As V2X deployments scale and more equipped vehicles are on the roadway, the indirect financial savings should be considered in any long-term, strategic investment.

It is important to note that V2X deployments also have the potential to achieve a host of other benefits beyond air quality, from improved roadway mobility to enhanced safety, and we believe that the vehicle idling measures discussed in this paper straddle lines regarding funding potential. We encourage interested readers to research similar opportunities in their jurisdictions if harnessing V2X technology to further roadway initiatives that target environmental improvement, roadway safety, and roadway mobility.

Conclusion

V2X technology can address our ever-growing air quality issues. The wealth of data that we receive from such technology deployments can provide several insights, and we have just begun to scratch the surface on the potential these V2X data offer. Utah has demonstrated that measuring vehicle idling metrics is possible using V2X technology, and we hope future advancements to this research will show that CIPT can reduce emissions by minimizing the time a vehicle spends in a state of idle. As this technology scales, the positive impacts on air quality could exponentially increase beyond those estimated in this paper.

We suggest parties who are interested in deploying V2X technology or tracking on similar metrics using this technology start now by seeking funding, assistance, and partnerships to make this a reality in their home community. Monitoring and improving air quality is a global effort, one where we all play a role, because air quality is not solely bound to neighborhoods or countries; rather, each contributes individually to the whole state of air quality on our planet.

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[12] The cost of an average idle event in the study was $0.03. With almost 1,400 idle events per day, reducing the duration of a vehicle idle event through CIPT by just 4 seconds (a 15% reduction) could translate into an annual savings of $2,327 from these activities alone in a single geographic area. When considering the larger impact from CIPT on unnecessary stop and go vehicle activities (i.e., post-stop high acceleration events), the dollar amount may exponentially increase. Note that there can be a multitude of factors that impact these estimates, however, which may include variances in fuel price, fuel type (e.g., gas, diesel, or electricity), traffic congestion, and more.

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