PROJECT NARRATIVE

Figure 1. Overview of LADDMS Stage I results. (a) Community-centered engagement for vulnerable road users. (b) Emphasis on privacy and safety is disseminated through local media. (c) Automatic bus recognition within live viewing system for public transit integration. (d) Always-active live viewing system captures an impending near-miss (e) Mature data visualization tools operate in a browser as well as on mobile tech, such as a smart watch. (f) Live viewer deployment to the Nashville DOT Traffic Management Center (shown are 5 of the 7 sensor areas).

OVERVIEW / PROJECT DESCRIPTION

The *Leveraging Advanced Data to Deliver Multimodal Safety* (LADDMS) initiative is fundamentally changing how we look at transportation safety for vulnerable road users. The results from our Stage I project must be seen to be believed, visit http://ndot-laddms.mogi.io/ for a demonstration of the live status of the Stage I system.

LADDMS Stage I (*Figure 1*) provides a transformative vision that can be immediately grasped when viewing the live system. Through real-time visualization and data analysis, we can discover safety concerns that typically go unobserved. Using cutting-edge, privacy-preserving sensing, the system enhances safety for vulnerable users and assesses safety intervention 10x faster.

We successfully used community-centered engagement to deliver the following: 1) privacy-preserving sensors to generate high quality trajectories of vulnerable road users and vehicles, 2) real-time measurement of near-miss events, and 3) the quick response and evaluation of safety interventions. Our Stage I interventions showed a 30% decrease of high-speed driving and 75% reduction in out of crosswalk events in the target zone. Since our system continuously records data along the entire corridor, we can analyze whether interventions simply shift unsafe behaviors to another nearby intersection.

Summary of Stage II goals: Our goal is to improve the safety of vulnerable road users along the Nolensville Pike corridor (see *Figure 2*) and continue to improve safety along the Stage I corridor. The approach is to deploy sensing, analytics, and interventions

piloted in Stage I at scale. Locations are prioritized for pedestrian and cyclist safety along the *High Injury Network* (HIN) in Nashville's Vision Zero Action Plan (https://www.nashville.gov/departments/transportation/plans-and-programs/vision-zero/action-plan).

Figure 2. Nolensville Pike (from I-40 to Harding Pl.), a Stage II LADDMS location, shows pedestrian risks.

People who live along the proposed corridors are more likely to rent their homes, identify as people of color or Hispanic, and have income below 200% of the federal poverty line compared to Nashville as a whole. These communities rank in the 79th percentile nationwide for insecurity from transportation safety per the Climate & Economic Justice Screening Tool.

LADDMS is led by NDOT and supported by *Metro Information Technology Services* (Metro ITS), Tennessee State University (a Historically Black College and University), The University of Tennessee Chattanooga, Vanderbilt University, Ouster, and *Tennessee Department of Transportation* (TDOT).

Real-world issues and challenges

Currently, NDOT relies on crash reports from the Nashville Police Department to identify areas of safety concern, which often lack the detailed information necessary for thorough safety analysis. It is estimated that 44-75% of pedestrian crashes and 7-46% of bicyclist crashes are not reported to NDOT. Also, there is no established method for tracking "near-misses" involving pedestrians or cyclists. These significant gaps prevent widespread understanding of the links between pedestrian safety and effective interventions.

Improving the status quo

This project will also address injuries and near-misses at mid-blocks, which are often overlooked. It directly supports NDOT transportation goals to count vulnerable road users and near-misses, enhance community partnerships, and expand secure data access for smarter transportation networks.

> *LADDMS is a vital component of Nashville's broader Vision Zero strategy to eliminate all traffic-related deaths and severe injuries and at the same time, increasing safety, equity, and mobility for all users.*
>
> *~ Diana Alarcon, NDOT Director*

Adopted technology

LADDMS uses lidar sensors to detect vulnerable road users and vehicles ten times per second. The sensors are connected to an edge computer that automatically converts the raw detection data into trajectories of road users (*Figure 3*).

Trajectories are continuously processed to provide high quality counts, positions, and near-misses between vehicles and vulnerable road users in real-time.

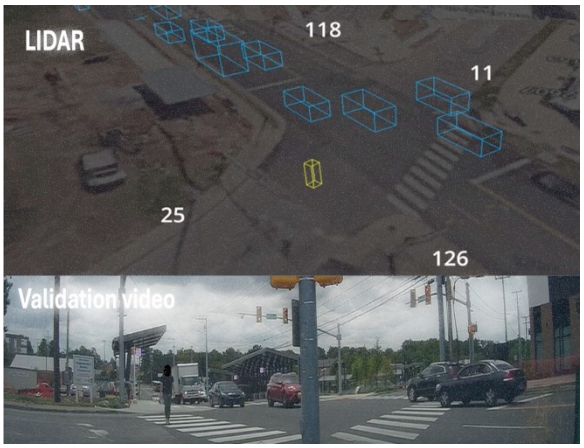

Figure 3. Top: lidar automatically detects bounding boxes of vehicles (blue) and pedestrians (yellow). Bottom: validation video used to verify count accuracy.

Table 1: Stage I activities and outcomes	
Activity: Community Engagement. We held community engagement events in North Nashville, including interviews with bus passengers and pedestrians. We received feedback on speeding and unsafe mid-block crossings. Community members raised the need for a camera-free solution, which motivated our pivot to lidar. We shared the project findings in keynote talks at academic and industry events, reaching an estimated 589 participants. **Activity: Workforce development.** We provided technical trainings on lidar ITS systems to 26 workers at the two largest traffic signal contractors in Central TN: Stansell Electric and NABCO Electric. TSU LADDMS students placed 3rd in the 46th Annual Research Symposium at TSU. **Activity: Installation and technology demonstration.** Our team installed 13 lidar sensors at 8 locations and created new and robust live visualization and continuous data analytics tools.	**Outcome: Near-miss detection.** We identified near-miss events that were previously impossible to capture through traditional NDOT sensing or crash reporting. On average, we observe 6.6 near-miss events between pedestrians and vehicles per day (quantified as a *post encroachment time* less than two seconds). **Outcome: High quality counts on all road users.** Following our 90-day burn-in period, counts of pedestrians and bicycles were found to be within 2% of the ground truth. This directly supports NDOT's Vision Zero Action plan to implement a robust active transportation user count program. **Outcome: Community impact.** We designed and deployed two safety interventions that reduced out of crosswalk events in the target zone by 75% and reduced the share of speeding vehicles by 30%.

Activities & outcomes of Stage I

Activities and outcomes of Stage I are shown above in Table 1.

Anticipated Stage II outcomes

Our Stage II goal is to set the standard for safe operation of corridors for all road users through targeted Vision Zero interventions.

- **Deployment and Community Impact.** Our Stage II lidar deployment will observe 45,000,000 vehicle miles of travel annually, implement safety interventions, and evaluate their effectiveness. The proposed project extents experienced at least 39 serious injury or fatality crashes involving pedestrians since Jan. 1, 2023.
- **Real-time Vulnerable Road User Counts.** Uncover usage patterns and trends through continuous observation, which will improve our ability to understand fundamental safety issues and the effectiveness of interventions.
- **Continuous Analysis/Safety Analytics:** Based on baseline data from Stage I, we may identify up to 180 near-miss events per day, which we will compare with comprehensive crash and injury data.
- **Community Engagement:** Building on valuable community feedback during Stage I, we will expand engagement activities into the Stage II project corridor.
- **Workforce Development:** We will expand our training programs, partnering with new agencies outside of middle Tennessee that have not used lidar. Dissemination of software and results through organizations such as ITE, ITS Tennessee, and ITS America will further support workforce development goals.

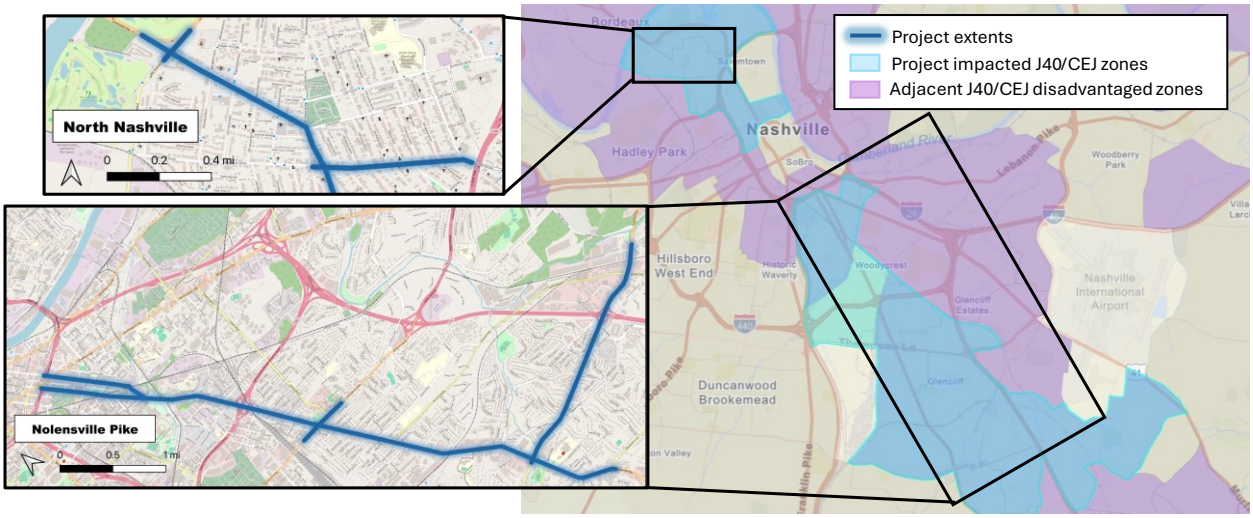

Figure 4. LADDMS lies entirely in disadvantaged areas per the Climate and Economic Justice Screening Tool.

Addressing SMART goals

Key goals include expanding advanced **safety** measures to new portions of the high injury network. The project aligns with NDOT's Vision Zero plan to reduce crashes and to improve crash data collection with a focus on vulnerable road users. **Equity goals** focus on improving access and safety for historically disadvantaged communities and promoting local **workforce development** through partnerships with TSU and other local organizations. **Community engagement** and partnerships will be fostered through public survey events and collaborations with the private sector. **Workforce development** will focus on training electricians and increasing collaboration between university researchers and NDOT staff. The project will **enhance the reliability and cybersecurity** of the transportation system through direct partnership with Metro ITS. **Climate goals** are supported through improved access to non-motorized travel modes and addressing inefficiency in corridor signal operations.

PROJECT LOCATION

The project is in the Nashville-Davidson urban area (*Figure 4*). Stage II builds upon the successful Stage I deployment in the North Nashville community and expands to the Nolensville Pike community, another area with a highly multimodal transportation landscape that is in significant need of safety study and improvement (See the 2022 Nolensville Pike Study available at: https://www.nashville.gov/sites/default/files/2022-08/Nolensville_Pike_Study.pdf).

The project-impacted Census tracts (2020 definitions) are situated entirely within disadvantaged areas according to the *Climate and Economic Justice Screening Tool*. Five HUD Opportunity Zones are covered by the project. Additionally, 97.7% of the population in the project-impacted tracts qualify as disadvantaged by the *USDOT Equitable Transportation Community (ETC) Explorer* criteria. The tracts qualify as disadvantaged in 21 of the 40-component metrics under climate, environmental, health, social, and transportation ETC categories.

TECHNICAL MERIT OVERVIEW

NDOT, through its Vision Zero Action Plan, is committed to eliminating roadway injuries and fatalities. To achieve this, several problems must be overcome.

Problems to be Solved

Problem 1. Limited count data on vulnerable road users. NDOT is in the early stages of implementing a pedestrian count program. Unfortunately, traditional approaches to collect vulnerable road user data are costly, labor intensive, and intermittent, which means the resulting data is limited and updated infrequently.

Problem 2. No method to collect near-miss data, which could enable pro-active safety. NDOT has already maximized the use of traditional crash reporting measures to define the High Injury Network. The HIN can be used for targeting corridors for safety interventions, but it is a reactive rather than pro-active approach to safety. Currently, NDOT does not have any mechanism to collect *surrogate safety measures* such as near-miss events (*Figure 5*), which can help identify safety issues for vulnerable road users before they result in crashes.

Problem 3. Long feedback loops to evaluate safety interventions. The traditional process to evaluate interventions can take years to determine if the desired outcomes are achieved. There are no existing approaches that allow early measurable insights into intervention performance.

Appropriateness of the Solution

By expanding our approach in Stage I with lidar sensors, we can address all problems mentioned above. The technology solution accurately counts pedestrians and other road users and detects near-misses. Our Stage I results show that the project allows Vision Zero interventions to be quantitatively assessed rapidly, with real-time views and early intervention impact analysis within just 24 hours.

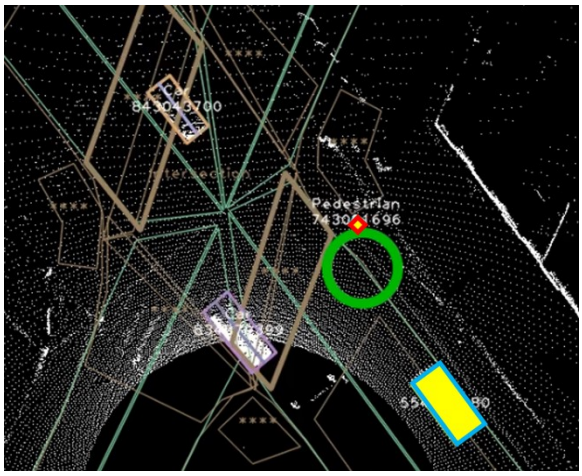

Figure 5. A near-miss is automatically detected on July 13, 2024. The vehicle (yellow rectangle with blue outline) and pedestrian (yellow square with red outline) are part of a near-miss event that occurs over subsequent frames in the green circle. Colors are enhanced for readability.

Scale and reproducibility. A key result of Stage I was demonstrating that existing network, power, mounting poles, and production software can allow the solution to scale quickly to new locations. New installations can be configured and integrated with existing data pipelines within 2-3 hours per location. This provides useful data that can be viewed live and recorded for baseline analysis.

Lessons learned in Stage I. A key takeaway from the meaningful engagement we carried out in Stage I is that communities want safer streets, but do not want cameras. Our Stage I tools allow continued community engagement by showing live views of the data, helping the public to understand how the technology is privacy preserving while advancing the goal of safer streets.

Improvements over the status quo. The lidar sensors are continuously monitoring road conditions and have been validated to within 2% accuracy for pedestrian counts. The system provides live information and records anonymous data for extended analysis. This is a demonstratable

improvement over the status quo, which does not count vulnerable road users. Additionally, individual object trajectories provide high-fidelity data for advanced analytics, while preserving privacy.

Appropriate for planned location: Nolensville Pike is an active corridor in an area primarily populated by members of historically marginalized groups. Community feedback cites the road as dangerous for pedestrians and cyclists. This is despite its high-volume, priority bus routes. Pedestrian, bike, and transit accessibility are important aspects of the corridor's public transportation system; thus, safety must be improved.

Expected Benefits

The department and program priorities within Nashville include safety as a key metric, with a Vision Zero action plan to eliminate all traffic injuries and fatalities, and a Safe Streets for All program that includes funding for safety interventions to improve safety on Nolensville Pike. Current approaches require planning processes to establish useful interventions for safety, and measurement of success is carried out through mainly human means.

Our proven system can provide the needed evaluation data through sustained measurement and continuous analytics, to evaluate the initial effectiveness of an intervention within 24 hours. This will dramatically shorten the timeframe in which interventions can be evaluated, enabling Nashville to meet its aggressive goals.

Preliminary Findings from Stage I: As described above, the baseline data and interventions show the ability to detect near-misses, and to accurately measure pedestrian and vehicle traffic. The system maintains persistent monitoring, which we have demonstrated an ability to data mine for continuous analytics.

Performance Metrics: The system met or exceeded expectations on 12 metrics that our team evaluated as part of Stage I. We propose to include all those performance metrics in Stage II. The metrics are grouped by thematic area below:

- Sensor Accuracy: Counts of objects were within 2% of ground truth for (1) pedestrians and (2) vehicles. (3) Distance accuracy is within the noise floor of GPS, and speed estimates are within 1 m/s accuracy. (4) Real-time detection of near-misses to within a 95% true positive rate. (5) Vulnerable Roadway Users detection (manually verified).
- Continuous Availability: (6) Low-latency detection of road users (works in real time), (7) environmentally robust (>99% uptime for each sensor), (8) persistent measurement of near-misses (6.6 per day over 84 days), and (9) continuous analytics for each intersection with archived data.
- Usefulness for Intervention Design: (10) Accurate measurements of near-misses, (11) rapid evaluation of safety for pedestrians (75% improvement in target area), (12) rapid evaluation of safety for vehicles (30-35% improvement).

Our system will enable preliminary insights in less than 24 hours, and sustained insights thanks to the uptime availability and continuous analytics.

Reflection on performance metrics: Existing metrics for accuracy and availability are deemed useful by the proposing team. Metrics for usefulness will be interpreted by partners from the Vision Zero team as well as the LADDMS team.

PROJECT READINESS OVERVIEW

Workplan Summary

Our Stage I project is ahead of schedule thanks to the complete buy-in of community members, project partners, and local government leadership. In a single week in Stage I, we installed eleven sensors, detected excessive speeding, deployed a successful intervention, and validated it. Our proposed schedule for Stage II is equally ambitious, but achievable by this project team.

Months 1-4
• Stakeholder outreach begins, notice of project to surrounding neighborhood organizations and businesses • Systems Engineering Analysis, site visits, preliminary plans • Continue Stage I workforce training
Months 5-8
• NEPA review & utility coordination • Plans, specifications, and estimates • Lidar procurement • Community engagement, workforce development activities, data infrastructure deployment
Months 9-18
• Unit bench testing and lidar installation • Subsystem/system testing & integration
Months 18-24
• Burn in testing, data collection • Community engagement
Months 24-36
• Intervention deployment, data analysis, dissemination

Feasibility of Workplan

We confirm our system will be integrated with existing transportation systems, including transit. Based on our team's extensive experience with ITS deployment, our schedule is ambitious but feasible.

Legal/regulatory. We are familiar with the NEPA process and are committed to avoid right of way and environmental impacts to expedite NEPA review and ensure a Categorical Exclusion designation. We will follow all applicable procurement policies and sole source requirements to procure Ouster Buy America and Buy American certified lidar units. We will proceed with the justification process for Stage II equipment while this grant is under review.

Local utilities. We have a close working relationship with local utility agencies and we effectively engaged with them during our SMART Grant Stage I project. With our existing relationships with the local utility agencies, we will ensure early and frequent communication and coordination to address any utility conflicts and ensure readiness, such as for power and communications, prior to installing devices in the field.

Partners. We will be working with the same contractors from the LADDMS Stage 1 project. We will ensure early and frequent coordination to guarantee equipment is procured, tested, and installed in a timely manner. Our project partners are critical to our ability to meet the Stage II schedule milestones. We will build on and strengthen the partnerships developed in Stage I to ensure the successful and timely completion of the Stage II project.

Supply chain. NDOT will directly procure lidar units from Ouster to reduce procurement delays. In Stage I, the project team identified a standard set of equipment needed for intersection and mid-block installations, including cabinets, networking, and other equipment. Two pre-configured equipment installation form factors (*Figure 6*) were developed to accelerate field work. We are procuring devices early to allow bench testing

and configuration while other preparation activities are completed.

Figure 6. Two styles of pre-fabricated lidar equipment installations developed during Stage I. Left: a drop-in rack mount with lidar equipment, for traffic cabinets with sufficient space. Right: an accessory cabinet affixed onto existing signal cabinets.

Stage I feasibility learnings

Our Stage I grant taught us several valuable lessons that have been accounted for in our schedule. First, community engagement is critical, and helped us avoid camera-based technologies that raised community privacy concerns. Second, direct collaboration with Ouster accelerated our staff and workforce trainings and allowed us to troubleshoot issues quickly. Third, we have established a direct collaboration with Metro ITS at the planning stage of this project to improve our ITS security posture on the at-scale implementation.

Plans for physical safety and cybersecurity

All project partners follow a safety-first culture. The project goal is to improve safety of all road users, and as a privacy preserving sensing project, it has minimal direct risks to public safety. NDOT is working with Metro ITS to deploy *intermediate distribution frames* to the Nolensville Pike fiber network by June 2025 for this project. The system will operate on NDOT's internal network in accordance with their cybersecurity protocols.

Workforce Assessment

To advance workforce development and technology transfer, our Stage I project successfully prototyped a hands-on training program tailored for skilled electricians. This program equips them with the necessary skills to navigate the increasing use of technology in the transportation sector. The LADDMS team collaborated with electrical contractors Stansell Electric Company and NABCO Electric Company (International Brotherhood of Electrical Workers) during this prototyping phase, see *Figure 7*. Additionally, we conducted training sessions with Ouster, NDOT staff, and University partners.

Figure 7. NABCO IBEW team member assembling a lidar unit on a test bench during a workforce training session in Chattanooga, TN.

As we move into Stage II, we are introducing a new plug-and-play lidar strategy for peer departments of transportation around the country. Our implementation plan outlines the acquisition of 10 additional lidar bundles by LADDMS staff, along with the required auxiliary equipment (including switches, modems, power supplies, etc.). We will provide this equipment to other municipal and state transportation agencies at no cost to them through an intergovernmental agreement. Furthermore, our team will travel to partnering agencies to train their staff and contractors on the equipment usage and data analysis. Our expectation is to significantly reduce the learning curve for new communities adopting lidar technology, thereby expanding the benefits of the SMART grant beyond Nashville's boundaries.

In support of workforce development, NDOT actively promotes good-paying jobs with free and fair choice for union membership. This commitment aligns with the Metro Charter (Chapter 3.56), which recognizes employees' right to organize. Through our work, NDOT frequently collaborates with the Fire Union, Fraternal Order of Police, and the Service Employee International Union.

Beyond our direct partnership with TSU, Metro also focuses on entry and retention through the POWER Youth Summer Employment Initiative. This program provides career exploration and work experience activities for youth aged 14 to 24, particularly those underrepresented in infrastructure jobs. This initiative is executed through high school internships, direct hire or other external postings and work programs.

Metro's commitment to diversity, equity, and inclusion is evident through hiring policies and the appointment of a Chief Diversity Equity & Inclusion Officer within the central Human Resources department. Our policies include regular diversity and inclusion training to increase awareness and understanding of equity in the workplace.

In addition to Metro's internal hiring policies, the dedication extends to creating opportunities for Minority and Women-Owned Business Enterprise

Through ongoing procurement regulation changes, Nashville is implementing a race and gender-neutral program. The program will increase the ability for firms to form joint ventures or teaming arrangements and to obtain any needed support services. Metro is developing an enhanced communications plan for how it will better assist the MWBE business community in understanding its programs, implementations, and how to prepare for future opportunities.

Community-centered approach

The LADDMS team is a growing consortium of partners including Vanderbilt University, Tennessee State University, Tennessee Department of Transportation, and other local stakeholders.

Figure 8. LADDMS team member Tupac Moseley (TSU MS student) interviews a North Nashville resident to get valuable feedback on the LADDMS project and the use of lidar to improve safety. See the video on the project website at https://ndot-laddms.org.

As demonstrated in Stage I, a community-centered approach cultivated on meaningful, continuous, accessible engagement with a diverse group of stakeholders (*Figure 8*). The continued plan for Stage II is to maintain connections built in Stage I as well as to expand to new communities that will benefit from the at-scale implementation.

A recent public survey gathered community feedback from 580 people along Nolensville Pike. Key findings are: 79% of people feel uncomfortable or very uncomfortable biking, and 66% feel uncomfortable or very uncomfortable walking.

Our preliminary work validates this community concern. We performed a GIS analysis of all crash data from Metro Nashville police department. Hypothetically envisioning our project was constructed on Jan. 1, 2023, the sensors (80 m range) would have observed 1,935 reported property, injury and fatal crashes through July 17, 2024. This includes 630 injuries and 12 fatalities. Pedestrians were involved in 39 of the crashes of which 4 were fatalities, as is shown in

Figure 9. Map of injury and fatal pedestrian crashes within proposed Stage II extents. Fatal crashes are shown as orange stars and injury crashes as red circles. Specific roadways of project extents are outlined in blue.

Figure 9. These qualifications and risk factors have led to the designation in the Nashville High Injury Network for 100% of the project roadways.

Because of the magnitude of the need, a complementary investment in this corridor is underway with a Safe Streets for All (SS4A) grant, awarded to NDOT in 2023. The joint execution of the SS4A and SMART Grant will provide the opportunity to study pre- and post-intervention safety for pedestrians and other vulnerable road users in the highest possible fidelity. The high-quality data and near-miss metrics from lidar coverage of the corridor will provide location-specific results for interventions such as curb extensions, pedestrian hybrid beacons, pedestrian refuge islands, and signal timing adjustments. The data gained from full lidar coverage of the corridor will be invaluable for longitudinal studies of these interventions.

While we expect our interventions to be rapidly deployed, they may have unintended consequences. Our ability to rapidly measure the consequences allows us to make modifications before they have sustained negative consequences to the community.

NDOT has attracted support from community organizations through education and collaboration and we will continue to work within our community furthering our support through informative outreach. NDOT will continue outreach through the project website https://ndot-laddms.org/.

NDOT will continue our public information campaign from Stage I, including stakeholders and the public. As communities continue to diversify, we have placed emphasis on hiring multilingual staff who can more effectively communicate with our growing limited English proficiency populations. We anticipate the project benefits to effectively reach our low-income residents, transit riders, bicyclists, and pedestrians.

Leadership and Qualifications

NDOT, under Director Diana Alarcon, will lead this effort. Director Alarcon brings more than 30 years of experience in guiding cities through important periods of transportation and infrastructure growth. Robert White, *Transportation Systems Management and Operations* (TSMO) Manager for *Nashville Department of Transportation and Multimodal Infrastructure* (NDOT), will serve as project manager. Robert also oversees NDOT's, Intelligent Transportation Systems and Traffic Management Center operations. NDOT will be supported by Veda Nguyen, P.E. at AECOM. Previously at TDOT, Veda managed the Intelligent Transportation System Office, and the *Pedestrian Road Safety Initiative* (PRSI) program.

Resumes of our key university partners are available in Appendix I. Please see our website for a complete list of partners.