GRANT APPLICATION SUMMARY SHEET

Grant Name: U.S. DOT Intersection Safety Challenge 24-26

Department: NDOT

Grantor: U.S. DEPARTMENT OF TRANSPORTATION

Pass-Through Grantor (If applicable):

Total Applied For $100,000.00

Metro Cash Match: $0.00

Department Contact: Casey Hopkins
8801676

Status: NEW

Program Description:

The Nashville Metro Area faces challenges in ensuring optimal safety at critical intersections. Current systems lack real-time adaptability, scalability, and data-centric prediction capabilities, increasing vehicle and road user vulnerability. There's an imminent need for an intersection safety software system for four pivotal intersections that employs Federated Machine Learning. This technology can analyze and predict traffic patterns without central data storage, ensuring efficient response while maintaining user privacy. The system must include sensing and perception features to predict vehicle and road user behaviors.

Plan for continuation of services upon grant expiration:

Apply for phase 2 of the Challenge if the data collected determines a need.

APPROVED AS TO AVAILABILITY OF FUNDS:

Kelly Flannery/mjw 9/25/2023 | 8:11 AM CDT

Director of Finance RW AP **Date**

APPROVED AS TO FORM AND LEGALITY:

Courtney Mohan 9/25/2023 | 11:09 AM

Metropolitan Attorney **Date**

APPROVED AS TO RISK AND INSURANCE:

Balogun Cobb 9/25/2023 | 8:18 AM CDT

Director of Risk Management Services **Date**

Freddie O'Connell 9/25/2023 | 1:09 PM

Metropolitan Mayor **Date** kW

(This application is contingent upon approval of the application by the Metropolitan Council.)

Grants Tracking Form

Part One

Pre-Application ◉ Application ○ Award Acceptance ○ Contract Amendment ○

Department	Dept. No.	Contact	Phone	Fax
NDOT	042	Casey Hopkins	8801676	

Grant Name:	U.S. DOT Intersection Safety Challenge 24-26		
Grantor:	U.S. DEPARTMENT OF TRANSPORTATION	**Other:**	
Grant Period From:	01/01/24	(applications only) **Anticipated Application Date:**	09/22/23
Grant Period To:	01/01/26	(applications only) **Application Deadline:**	09/25/23
Funding Type:	FED DIRECT	**Multi-Department Grant**	☐ → If yes, list below.
Pass-Thru:	Select Pass-Thru --- >	**Outside Consultant Project:**	☐
Award Type:	COMPETITIVE	**Total Award:**	$100,000.00
Status:	NEW	**Metro Cash Match:**	$0.00
Metro Category:	New Initiative	**Metro In-Kind Match:**	$0.00
CFDA #		**Is Council approval required?**	☑
Project Description:		**Applic. Submitted Electronically?**	☑

The Nashville Metro Area faces challenges in ensuring optimal safety at critical intersections. Current systems lack real-time adaptability, scalability, and data-centric prediction capabilities, increasing vehicle and road user vulnerability. There's an imminent need for an intersection safety software system for four pivotal intersections that employs Federated Machine Learning. This technology can analyze and predict traffic patterns without central data storage, ensuring efficient response while maintaining user privacy. The system must include sensing and perception features to predict vehicle and road user behaviors.

Plan for continuation of service after expiration of grant/Budgetary Impact:

Apply for phase 2 of the Challenge if the data collected determines a need.

How is Match Determined?

Fixed Amount of $ ____ or ____ **% of Grant** ____ **Other:** ☐

Explanation for "Other" means of determining match:

For this Metro FY, how much of the required local Metro cash match:

Is already in department budget?	$0.00	**Fund**	N/A	**Business Unit**	N/A
Is not budgeted?	$0.00	**Proposed Source of Match:**			N/A

(Indicate Match Amount & Source for Remaining Grant Years in Budget Below)

Other:

Number of FTEs the grant will fund:	0.00	**Actual number of positions added:**	0.00
Departmental Indirect Cost Rate	18.83%	**Indirect Cost of Grant to Metro:**	$18,830.00
***Indirect Costs allowed?** ○ Yes ◉ No **% Allow.**	0.00%	**Ind. Cost Requested from Grantor:**	$0.00 **in budget**

***(If "No", please attach documentation from the grantor that indirect costs are not allowable. See Instructions)**

Draw down allowable? ☐

Metro or Community-based Partners:

Tennessee State University

Part Two

Grant Budget

Budget Year	Metro Fiscal Year	Federal Grantor	State Grantor	Other Grantor	Local Match Cash	Match Source (Fund, BU)	Local Match In-Kind	Total Grant Each Year	Indirect Cost to Metro	Ind. Cost Neg. from Grantor
Yr 1	FY24	$100,000.00	$0.00	$0.00	$0.00	N/A	$0.00	$0.00	$18,830.00	$0.00
Yr 2	FY__									
Yr 3	FY__									
Yr 4	FY__									
Yr 5	FY__									
Total		$100,000.00	$0.00	$0.00	$0.00		$0.00	$0.00	$18,830.00	$0.00

Date Awarded:		**Tot. Awarded:**		**Contract#:**	
(or) **Date Denied:**		**Reason:**			
(or) **Date Withdrawn:**		**Reason:**			

Contact: juanita.paulsen@nashville.gov
vaughn.wilson@nashville.gov

Rev. 5/13/13
5705

GCP Rec'd
09/21/23

GCP Approved
09/21/23

VW

U.S. DOT Intersection Safety Challenge:
Stage 1A (Concept Paper) Prize Competition Description for Participants

Contents

Version	Publication Date	Description of Changes
Original	4/25/2023	N/A
Revision 1	7/26/2023	Figure 1 – months revised. Table 1 – dates revised.

Note: *This document constitutes the complete official terms and conditions for Stage 1A (Concept Paper) Prize Competition of the U.S. DOT Intersection Safety Challenge. U.S. DOT reserves the right, in its sole discretion, to (a) cancel, suspend, or modify the Challenge, and (b) not award any prizes if no entries are deemed worthy. Any modifications to Stage 1A of the U.S. DOT Intersection Safety Challenge will be reflected in this document.*

I. Summary

Improving the safety of pedestrians, bicyclists, and other vulnerable road users is of critical importance to achieving the objectives of the U.S. Department of Transportation (DOT) National Roadway Safety Strategy (NRSS) and DOT's vision of zero fatalities and serious injuries across our transportation system. According to data from the National Highway Traffic Safety Administration (NHTSA), 10,626 traffic fatalities occurred at roadway intersections in the United States in 2020, including 1,674 pedestrian and 355 bicyclist fatalities. These fatalities at intersections represent 27% of the total of 38,824 road traffic deaths recorded in 2020. Preliminary estimates for 2021 point to further increases, with pedestrian fatalities up 13% and pedalcyclist fatalities up 5% compared to 2020 (NHTSA, May 2022).

In response to these growing concerns and as part of DOT's continued implementation of the NRSS, the DOT Intersection Safety Challenge (hereafter, "the Challenge") aims to transform intersection safety by incentivizing the innovative application of new and emerging technologies to identify and mitigate unsafe conditions involving vehicles and vulnerable road users at intersections. The Challenge complements other Federal efforts to improve intersection safety, with the Challenge specifically focused on the use of technology. Further, the intersection environment itself is well-suited to innovative mitigative approaches leveraging, utilizing, and potentially repurposing existing traffic control and support infrastructure.

Of particular interest in addressing intersection safety is the development of systems that apply emerging capabilities enabled by advanced sensing, communications technologies, and artificial intelligence (AI) and machine learning (ML). These include machine sensing and perception, data fusion, trajectory and path prediction, vehicle-to-everything (V2X) communications, and real-time decision-making. Technological advancements in these and other areas offer an opportunity to improve intersection safety at scale in new and effective ways. The Challenge encourages the formation of non-traditional teams combining expertise in emerging technologies with experience in traffic and safety engineering to develop new and potentially transformative intersection safety approaches.

The Challenge also aligns with equity-related DOT priorities set forth in the Bipartisan Infrastructure Law (BIL). Improving intersection safety is a foundational element in enhancing equity and accessibility in many communities. Safe and reliable transportation, including access to and use of various transportation modes in and around intersections, can be a powerful engine of opportunity, connecting people to jobs, education, and resources. The Challenge supports DOT's equity priorities, as outlined in the *U.S. DOT Strategic Plan for FY 2022-2026*, the *U.S. DOT Equity Action* Plan, and the *National Roadway Safety Strategy*.

Overall, the Challenge aims to incentivize the development of new, cost-effective, real-time roadway Intersection Safety System (ISS) concepts (see Section IV). Further, to set the stage for future deployment nationwide, the potential safety benefits relative to the estimated costs of deploying new system concepts must be compelling enough to motivate equitable at-scale deployment across the nation.

II. Background

The Challenge seeks to incentivize the development of transformative, innovative intersection safety systems employing existing and emerging technologies. Many modern control systems, including emerging advanced intersection control systems, are increasingly reliant on real-time decision-making informed by data ingested and analyzed from advanced sensor systems. This includes safety-critical machine decision-making where human response times may be insufficiently rapid or lack comprehensive situational awareness. Often, powerful new control systems combine the strengths of both human and machine decision-making. One relevant example of mixed human/machine control is in vehicle automation. Here, the confluence of developments in sensing, data fusion, and AI are creating new and compelling Advanced Driver Assistance Systems (ADAS) and emerging Automated Driving Systems (ADS). Such systems may issue warnings to a human driver or independently implement safety-critical vehicle control decisions.

Anticipation, Prevention, and Mitigation of Unsafe Intersection Conditions

DOT is interested in the development of new safety systems that adapt salient emerging technologies to enhance real-time traffic and pedestrian control systems and support road user warning systems. Such safety systems are expected to anticipate, prevent, and mitigate unsafe intersection conditions, including impending collisions among and between vehicles and vulnerable road users.

Anticipation, prevention, and mitigation of unsafe conditions may take place on multiple time scales relevant to the safety-related control decisions under consideration, including imminent collisions in the intersection. Preventive or mitigating decisions and actions may be tailored based on the real-time (or anticipated) pedestrian, bike, and vehicle patterns of travel in the intersection. For example, in anticipation of a surge in pedestrian demand in one or more crosswalks, intersection control systems could dynamically implement or prohibit unprotected vehicular intersection movements where appropriate vehicle control indicators are present. These changes could be made in combination with complementary modifications to pedestrian and/or bike lane traffic control (e.g., extended stop or walk time for specific crosswalks). Modifications to control systems may be augmented with warning systems alerting vulnerable road users and/or drivers. Additional tailored warnings may be transmitted for wirelessly connected vehicles and mobile devices able to interpret and act on standardized safety-related messages. Finally, detailed data on categorized road user demand (including individual vehicle trajectory and/or user paths through and around an intersection) could inform longer-term decisions regarding the intersection safety, including the installation of (or upgrade to) more capable traffic control systems, geometric changes, and/or the modification of local safety-related policies.

Vulnerable Road Users

The Challenge utilizes the definition of a "vulnerable road user" consistent with the Highway Safety Improvement Program: a non-motorist with a fatality analysis reporting system (FARS) person attribute code for pedestrian, bicyclist, other cyclist, and person on personal conveyance as defined in the ANSI D16.1-2007. (*Se* 23 U.S.C. 148(a)(15); 23 CFR 490.205). Under this definition, a vulnerable road user may include people walking, biking, or rolling but does not include a motorcyclist. Note that this definition of a vulnerable road user is specific for this Challenge. DOT considers a broader definition in some studies and/or countermeasure development depending on the circumstances.

For the Challenge, *vulnerable road users* are defined in accordance with this definition as pedestrians, cyclists, and most micro-mobility device users, including users of wheelchairs, scooters, skateboards, and other conveyances, of all ages and abilities. Likewise, for the Challenge, *vehicles* are defined as all motorized roadway vehicles including passenger cars, motorcycles, trucks, vans, public transit vehicles (including buses, light rail vehicles, and streetcars), and commercial vehicles. E-bikes and other micro-mobility conveyances capable of operating above 30 miles per hour are treated as motorcycles.

Whatever the general road user type, a critical differentiator is the class of intersection control assigned to an individual road user in an intersection at any point in time. For example, cyclists are vulnerable road users but are subject to vehicular traffic control when they travel in general roadway lanes. In a bike lane, a cyclist may be subject to bike-specific controls and policies that differ from general roadway lanes. Further, where bike lanes are present, e-bikes up to a certain size or power may utilize these lanes subject to local policy and regulations, and in this case may also be subject to bike-specific controls and policies. Generally, bikes are not allowed on sidewalks unless the cyclist dismounts. A dismounted cyclist pushing a bike is subject to pedestrian controls and may utilize crosswalks. Likewise, low-speed motorized scooters allowed under local policy to utilize sidewalks are subject to pedestrian control indicators, signage, and regulations.

In this Challenge, DOT is interested in enhancing holistic intersection safety including within roadway lanes, bike lanes, crosswalks, and sidewalks. In particular, the Challenge seeks specific system solutions that can detect and classify a comprehensive range of road users in real-time and detect or anticipate their individual movements in or across an intersection over time. This desired capability explicitly includes the transition of a single individual subject from one form of intersection control to another, e.g., a dismounted cyclist on a sidewalk mounting a bicycle, entering a bike lane, and then traversing an intersection. The envisioned capabilities must also perform equally across a range of vulnerable road user physical characteristics, including race/ethnicity, gender, age, clothing, size, and the use of adaptive equipment like wheelchairs, mobility scooters, and service animals.

Intersection Safety Improvement at Scale

To improve intersection safety at a national scale, cost-effective safety systems are needed that can ultimately be suitable for broader, nationwide deployment. DOT recognizes that a technology-based approach is one of many potentially cost-effective approaches for improving safety at intersections. Cost-effective approaches are also critical to support equity and accessibility considerations, in that deployment, operations, and maintenance requirements must be low enough to be applied broadly across the nation’s communities. The innovations sought in the Challenge operating in a real-time context are intended to augment (but not substitute for) a comprehensive suite of intersection safety considerations, including alternative intersection geometric design and changes to local traffic safety regulations and policies. The Challenge aligns with the NRSS and complements current and existing DOT safety efforts, such as the FHWA Complete Streets Program and FHWA Proven Safety Countermeasures.

To better understand the technologies that could enhance intersection safety, the DOT published the *Enhancing the Safety of Vulnerable Road Users at Intersections; Request for Information* (RFI) in the

Federal Register (commenting closed on November 15, 2022). Specifically, the RFI sought information on a conceptual vulnerable road user and vehicle warning system building on existing and emerging vehicle automation technologies that could be implemented at intersections. Such an intersection safety system concept might incorporate machine vision, perception, sensor fusion, real-time decision-making, AI, and V2X communications (among other possible approaches). The RFI responses pointed to a wide range of both existing and emerging technologies that could be integrated into intersection safety systems in the near-term.

III. Challenge Vision, Objectives, and Structure

Challenge Vision and Objectives. The vision of the Challenge is to *transform intersection safety through the development of one or more innovative intersection safety systems that identify, predict, and mitigate unsafe conditions involving vehicles and vulnerable road users in real-time*.

The Challenge seeks broad innovation in real-time roadway intersection and transit right of way safety featuring anticipatory warning systems and other safety-countermeasures for both drivers and vulnerable road users. Such intersection safety systems must be cost-effective in order to expedite their equitable deployment at scale at the highest risk intersections throughout the nation. In addition to technical considerations, successful systems must also consider a range of additional factors related to their suitability for at-scale deployment, including commercialization and mass-production feasibility, as well as factors related to the needs and constraints of both industry and Infrastructure Owners and Operators (IOOs).

Challenge Structure. DOT anticipates an overall Challenge structure and timing similar to the one illustrated in **Figure 1** below. (Note: The structure and timing presented is preliminary in nature and subject to change at any time at the sole discretion of the DOT.)

The Challenge begins with a two-part prize competition. Participants can include individuals, organizations, or teams of individuals and organizations, in accordance with the eligibility criteria below. While not a requirement for participation, teaming is encouraged to ensure that the participants possess the wide range of interdisciplinary skills required to ultimately produce a viable intersection safety system. Teams are encouraged further to consider system requirements unique to field deployment (as specified or recommended by IOOs) early in the system development process. In the first part of the prize competition (Stage 1A), participants submit a Concept Paper describing their intersection safety system concept and the potential of this concept to address the vision and objectives of the Challenge. Up to ten (10) awards will be made in Stage 1A to participants whose submissions demonstrate a comprehensive understanding of the problem and who propose a compelling and innovative solution to the safety problem posed.

In Stage 1B, participants will test their proposed system using real world sensor data collected on a closed course to assess the solution's potential to enhance intersection safety. At a minimum, winners from the first part (Stage 1A) will be eligible to participate in the second part (Stage 1B) of the Challenge. Depending on the results achieved during Stage 1A, DOT may choose to broaden Stage 1B eligibility. At the end of Stage 1B, if sufficiently compelling and innovative candidate intersection safety systems are identified, DOT may choose to fund follow-on projects in a second stage. These projects would involve prototyping and demonstration of candidate intersection safety systems under a competitive Broad Agency Announcement (BAA) or other procurement mechanism.

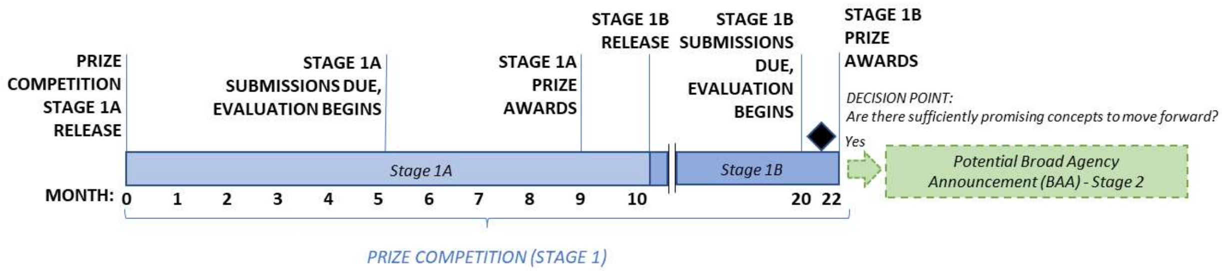


Figure 1. DOT Intersection Safety Challenge Structure and Schedule (Preliminary)

DOT Intersection Safety Challenge Stage 1: Prize Competition

Stage 1A: Concept Assessment — Participants submit an ISS Concept Paper (See Section VIII, *How to Enter*). Up to ten (10) well-formed, differentiable concepts scoring highest against a set of uniform judging criteria (see Section VI and VII, *Rules* and *Judging*, respectively) will receive a Challenge prize and may advance to the next part of the Stage 1 Prize Competition.

Stage 1B: System Assessment and Virtual Testing. Participants develop, train, and improve algorithms for the detection, localization, and classification of vulnerable road users and vehicles using DOT-supplied sensor data collected at a controlled test intersection. Further, participants will use these data and algorithms in real-time to predict future intersection conditions and identify potentially unsafe conditions and events. Entries will be scored using a rubric testing the accuracy of algorithms against observed ground truth conditions. DOT will provide information regarding the perception and prediction competition of Stage 1B after Stage 1A awards are made.

In addition, Stage 1B participants may also submit an ISS Concept Paper (as in Stage 1A). This may be a revised concept paper reflecting insights gained in participation in this prize competition.

Multiple Stage 1B submissions may receive a Challenge prize. Detailed rules and judging criteria will be provided prior to the start of Stage 1B.

Note: Participants are <u>not</u> required to demonstrate ISS deployments within real-world intersections in either Stage 1A or Stage 1B.

Anticipated Schedule: DOT anticipates that Stage 1 of the Challenge will proceed according to the tentative schedule outlined below (Table 1). Dates are subject to change with any changes being posted on the DOT's Challenge website accordingly.

Table 1. Outline of Challenge Schedule (subject to change)

Stage	Description	Date
1A	Launch	Late April 2023
1A	Close	September 2023
1A	Selection and Awards	December 2023 – January 2024
1B	Launch	January 2024 – February 2024

Stage	Description	Date
1B	Close	December 2024
1B	Selection and Awards	February 2025

DOT Intersection Safety Challenge Stage 2: Potential Broad Agency Announcement (BAA) Solicitation (optional)

Informed by the technical maturity of the intersection safety solutions offered in the Stage 1 prize competition and their potential to result in transformative safety impacts, DOT will determine whether to proceed to a second stage of the Challenge. In this potential second stage, DOT may issue a Broad Agency Announcement (BAA) solicitation (open to any eligible entities, whether or not an entity was a Stage 1 participant) to develop, test, and demonstrate one or more prototype ISS. Other procurement mechanisms besides a BAA may also be considered for Stage 2.

IV. The Intersection Safety System (ISS) Concept

Conceptually, an ISS would be deployed at a roadway intersection to modify or adapt intersection controls dynamically and warn drivers and vulnerable road users of potential impending collisions and/or conflicts. **Figure 2** presents a high-level overview of the anticipated elements of an ISS concept. Note that the ISS System of Interest (SOI) is identified as a shaded area in Figure 2, separate from the road users and other intersection infrastructure outside the boundaries of the ISS. Note further that this is a *conceptual* system, and as such is not intended to be prescriptive or represent a complete design.

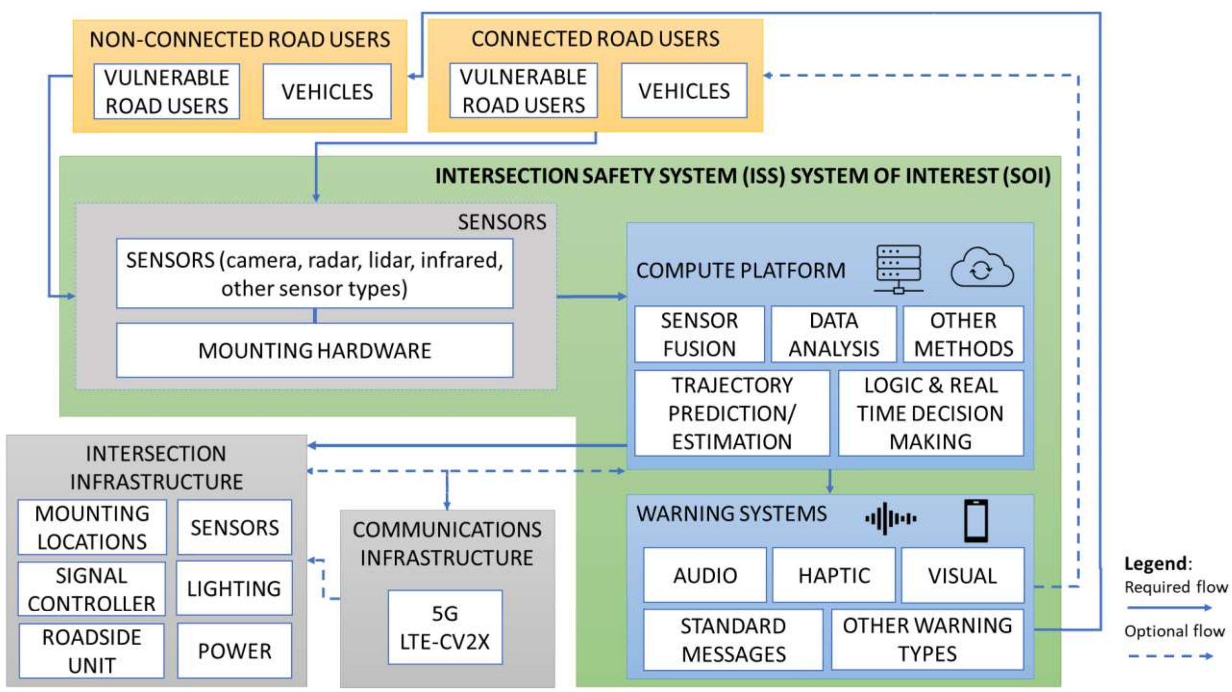


Figure 2. Conceptual Intersection Safety System Context Diagram

The ISS integrates and analyzes sensor data in real-time on a computing platform that hosts the required software elements and machine learning algorithms. The ISS ingests and analyzes sensor data to differentiate, classify, and localize individual vehicles and vulnerable road users in real-time. Further, the ISS predicts the real-time movements and future trajectories of individual vehicles and vulnerable road users within and in the immediate vicinity of the intersection (e.g., on adjacent sidewalks) and transit right of way. As mentioned above, these vehicle movements will include activities specific to transit vehicles and commercial vehicles. The ISS then issues coordinated messages to adapt or modify intersection control configurations in real-time in advance of potentially unsafe conditions and/or generate warnings regarding potential imminent collisions. An ISS must be capable of issuing warnings to drivers and vulnerable road users with no wireless connectivity. Warnings may be issued to wirelessly connected vehicles and vulnerable road users as well. Whether through wireless transmission of alerts or other methods, innovative approaches are sought to ensure that drivers and vulnerable road users can be alerted in an effective and timely way to prevent or mitigate unsafe conditions.

Participants in this Challenge will be asked to consider a range of relevant technologies, assess the potential for re-purposing both existing and emerging technologies to create an ISS concept aligned with the ultimate goal of at-scale deployment within, at most, 10 years. In particular, the Challenge seeks solutions with the potential to be cost-effectively deployed across the nation at a large proportion of the highest-risk intersections. The use of commercially available sensors and associated mass-produced componentry (for computation, networking, connectivity, and communication) may result in lower system costs when deployed at scale.

Intersection Safety System Costs. As an overarching goal, the Challenge seeks ISS solutions that utilize core componentry costing in the order of $10,000 (or less) per intersection at scale within 10 years following the end of the competition. *At scale* in this instance refers to targeted deployments in the order of 100,000 intersections nationwide. Note: The target cost figure pertains only to the cost of ISS-specific hardware and software for the SOI elements shown in Figure 2. Costs associated with the existing intersection geometrics, traffic control systems, power, communications backhaul, and other considerations outside the SOI in Figure 2 are ***excluded*** from this cost target. Further, all other ISS development, deployment, and operational costs, including but not limited to research and development amortization, installation, calibration, testing, training, operations, maintenance, and replacement are ***excluded*** from this cost target.

ISS Deployment Scope. A single ISS concept may not be suitable for implementation at all roadway intersections. The Challenge seeks one or more interoperable ISS solutions that can collectively address a large proportion of our nation's intersections and make a significant improvement in overall road safety. Note that an ISS concept that is intended only for intersections with specific characteristics or which addresses a specific intersection safety use case *may* be submitted for this Challenge. Other ISS concepts may target a broader deployment footprint and a wider range of use cases.

Minimum ISS Capabilities. An ISS should (at a minimum) have the following capabilities:

- Sensing and perception – The ISS must support the detection, localization, and classification of a number of individual vehicles and vulnerable road users simultaneously in real-time, while maintaining privacy protections. Sensing and perception of vulnerable road users must perform equally across skin tones, clothing, and other physical characteristics. An ISS perception system should sense intersection activity under a range of weather and visibility conditions. This includes variable ambient lighting, temperature, precipitation, visibility, glare, and other considerations that may impact sensing and perception. This capability may necessitate the utilization of diverse and/or redundant systems for higher reliability. The resolution, bandwidth, latency, power consumption, and cost of the vision and perception system are important considerations. Precise timing (derived from global navigation satellite systems [GNSS] or secondary or back-up sources that can be space- or land-based) may be employed.

- Vehicle and road user movement prediction – The ISS must predict the movements or trajectories of multiple vehicles and vulnerable road users in and near the intersection in real-time. Simultaneous road user and vehicle movements must be predicted contemporaneously to identify potential unsafe conditions or impending conflicts or collisions. The ISS shall detect potential collisions or other unsafe conditions and plan feasible mitigating actions that reflect a number of common intersection scenarios. Scenarios should be considered where road users both conform to intersection control direction (e.g., a pedestrian who waits to enter a crosswalk until a WALK signal is given), as well as cases where road users deviate (e.g., a pedestrian entering a crosswalk before a WALK signal is given).
- Data handling and storage – The ISS must be capable of managing the volume, bandwidth and variety of data required to enable all minimum capabilities. This includes event reporting covered below. This also includes data storage and archiving requirements, with attention paid to anonymization, privacy, and cybersecurity threats. Local storage as well as cloud- or edge-based data management systems may be considered.
    - Note that the *ISS itself* must be capable of independent data management supporting the functions related to real-time intersection control system adaptation and warning system control. Further, the ISS must be capable of providing detailed road user path/trajectory data (both observed and predicted) for external asynchronous safety engineering analysis.
- Wireless Communications and Positioning – A roadside unit or other form of infrastructure may be included if the proposed ISS concept utilizes some form of wireless connectivity—perhaps to include 5G connectivity, V2X, Wi-Fi, or other near-field communications. In addition, infrastructure-based positioning may support GPS or its equivalent.
- Intersection control system interaction – The ISS should be capable of real-time interconnection with existing modern intersection control systems (assume, at minimum, compliant with prevailing industry standards and protocols). The ISS may specify a collection of complementary actions related to the classes of road users at a particular intersection where there are differentiable control mechanisms: e.g., traffic signal or dynamic signage for vehicles, separate indicators and dynamic signage for bike lane users, and pedestrian indicators. The roadside infrastructure may be assumed to provide secure interconnection to the intersection traffic signals (via a signal cabinet for example) and to a central traffic management system for that jurisdiction (potentially through a wireless or fiber optic link).
- Warning system – The ISS must feature a vulnerable road user and vehicle warning system (or both vulnerable road user and vehicle warning systems). Such a warning system(s) may require one or more alarm types ranging from audible alarms, visual alerts, and other more advanced real-time alerts, such as a warning to a wirelessly connected vehicle, for example. The warning

system(s) must be capable of alerting vulnerable road users who are visually or hearing impaired and offer ADA-compliant operation. Vulnerable road users cannot be assumed to have wireless connectivity.

- Interoperability and extensibility considerations – An interoperable and extensible ISS solution must not degrade the underlying existing safety of any intersection at which it is deployed. Interoperability considerations include integration with existing systems at intersections as well as coordination among neighboring intersections with a deployed ISS. Further, the ISS should:
    - be upgradeable by virtue of a modular hardware and software design;
    - use open architectures to the fullest extent possible, including features such as open-source software and Application Programming Interfaces (API) libraries to encourage integration with varied control systems;
    - utilize industry-accepted software development practices;
    - be intrinsically cybersecure; and
    - maintain data privacy protections.
- Event reporting for performance measurement and system improvement – Interaction between the ISS and the intersection control system must support recording both crash and near-miss events, including tagging those events to support further safety and operations analysis at the central traffic management system. This includes supporting retrospective analyses of false-positive and false-negative warnings, unintended consequences, and site-specific tailoring or optimization.

High-Level ISS Requirements. An ISS should have the following high-level capabilities:

- Anticipate potential unsafe conditions and identify appropriate and timely traffic control system plans that can prevent or mitigate these conditions.
- Provide warnings to vehicles and vulnerable road users reliably, minimizing false positive and false negative warnings. Warnings must be provided in a way that all vulnerable road users and drivers may be alerted, whether they are wirelessly connected or not.
- Maintain consistent and reliable system operation and performance under a range of potential operational conditions (including variable weather, visibility, and pedestrian and vehicle demand patterns).
- Provide a cost-effective safety solution (See Section IV, *ISS Incremental Costs* for additional context) that results in a demonstrated reduction in intersection crashes and vulnerable road user fatalities across a variety of roadway intersections.
- Have a feasible path to rapid commercialization and deployment within 10 years, including the ability to be calibrated or customized for individual intersection locations. At scale considerations include streamlined maintenance and operations requirements to ensure equitable and sustainable safety impacts over time.
- Allow upgradeability and modularity as well as interoperability and data transfer capability with existing signal operating systems and traffic management systems.
- Monitor performance of the system by defining, storing, and analyzing false positives, false negatives, crash and near-crash rates, and other unintended consequences.

V. Prizes

Participants will compete for an overall Challenge prize competition (Stage 1) purse of up to $6,000,000. Prizes will be structured as follows:

- Stage 1A: Concept Assessment
  - Up to 10 prizes may be awarded in Stage 1A, with a maximum of one prize awarded per participant or team.
  - Each Stage 1A prize will have a maximum of $100,000.
  - The total value of all Stage 1A prizes will be a maximum of $1,000,000.
- Stage 1B: System Assessment and Virtual Testing
  - Multiple prizes may be awarded in Stage 1B, with a maximum of one prize awarded per participant or team.
  - Each Stage 1B prize will have a maximum of $1,000,000.
  - The total value of all Stage 1B prizes will be a maximum of $5,000,000.

VI. Rules

Note: U.S. DOT reserves the right, in its sole discretion, to (a) cancel, suspend, or modify the Challenge, and (b) not award any prizes if no entries are deemed worthy.

Eligibility

The Challenge is open to individuals and teams (participants) from the academic, research, and business communities including, but not limited to, universities and other institutions of higher learning, research institutions, technology companies, and entrepreneurs. If any potential prize winner is found to be ineligible for any reason, including for failure to comply with Challenge rules, an alternate winner may be selected.

To be eligible to win a prize under this Challenge, an individual or entity (participant):

1. Shall register to participate in the Challenge under the rules as outlined in this document.
2. Shall comply with all the requirements under this announcement and any subsequently announced rules for the prize competition.
3. In the case of a private entity, shall be incorporated in and maintain a primary place of business in the United States or U.S. territory,
4. In the case of an individual, whether participating singly or as a part of a team, shall be a citizen or permanent resident of the United States or U.S. territory.
5. Shall not be a DOT employee; and
6. Shall not be another Federal entity or Federal employee acting within the scope of their employment (all non-DOT Federal employees must consult with their agency Ethics Official to determine whether Federal ethics rules limit or prohibit the acceptance of a cash prize stemming from a Federally sponsored prize competition).

In addition, these two restrictions apply to recipients of other Federal funds:

1. Federal grantees or recipients of Federal cooperative agreements may not use Federal funds to develop submissions for this Challenge unless consistent with the purpose of their grant award or cooperative agreement; and
2. Federal contractors may not use Federal funds from a contract to develop prize competition applications or to fund efforts in support of a prize competition submission.

Note: DOT reserves the right to disqualify any submission that it deems, in its discretion, to violate these Official Rules, Terms & Conditions.

Liability and Insurance Requirements

By registering and entering a submission, each participant agrees to assume any and all risks and waive claims against the Federal Government and its related entities, except in the case of willful misconduct, for any injury, death, damage, or loss of property, revenue, or profits, whether direct, indirect, or consequential, arising from their participation in this competition, whether the injury, death, damage, or loss arises through negligence or otherwise. By registering and entering a submission, each participant further represents and warrants that it possesses sufficient liability insurance or financial resources, *to the extent permitted by applicable law*, to cover claims by a third party for death, bodily injury, or property damage or loss resulting from any activity it carries out in connection with its participation in this competition, or claims by the Federal Government for damage or loss to government property resulting from such an activity. Competition winners shall be prepared to demonstrate proof of insurance or financial responsibility in the event DOT deems it necessary.

Payment of the Prize

Cash prizes awarded under this Challenge will be paid to the individual or Team Lead directly by DOT through electronic funds transfer. Winner(s) will be responsible for any applicable local, State, and Federal taxes and reporting that may be required under applicable tax laws. The DOT will comply with the Internal Revenue Service withholding and reporting requirements, where applicable.

Confidential and Business Information

Challenge submissions and communication with DOT are subject to the Freedom of Information Act (FOIA, 5 USC 552). If the application includes information that the applicant considers to be a trade secret or confidential commercial or financial information, the applicant should do the following: (1) Note on the front cover that the submission “Contains Confidential Business Information (CBI)”; (2) mark each affected page “CBI”; and (3) highlight or otherwise denote the CBI portions. DOT protects such information from disclosure to the extent allowed under applicable law. In the event DOT receives a FOIA request for the information, DOT will follow the procedures described in its FOIA regulations at 49 CFR 7.29. Only information that is ultimately determined to be confidential under that procedure will be exempt from disclosure under FOIA. DOT may proactively publish any application information that is not marked as CBI.

Representation, Warranties, and Indemnification

By entering the Challenge, each Applicant represents, warrants, and covenants as follows:

- Applicant is the sole author, creator, and owner of their Submission;

- The Submission is not the subject of any actual or threatened litigation or claim;
- The Submission does not and will not violate or infringe upon the intellectual property rights, privacy rights, publicity rights, or other legal rights of any third party;
- The Submission does not and will not contain any harmful computer code (sometimes referred to as “malware,” “viruses,” or “worms”); and
- The Submission, and contestants use of the Submission, does not and will not violate any applicable laws or regulations.

If an Applicant is unable to make any of the warranties as stated above, Applicant must provide a clear written explanation of the reason(s) it cannot make any specific warranty. DOT will, in its sole discretion, determine whether such explanations are sufficient.

Intellectual Property of Submissions

Applicants can utilize intellectual property developed prior to this prize competition as a part of their Submission. Neither the DOT nor anyone acting on its behalf will obtain any rights in intellectual property developed prior to or during Stage 1A or Stage 1B of this prize competition without the prior written consent of the Participant. By participating in the prize competition, the Participant is not granting rights in any patents, pending patent applications, or copyrights related to the technology described in their submission. However, by submitting their entry, the Participant is granting the DOT and any parties acting on its behalf certain limited rights as set forth herein.

By virtue of their submission to this prize competition, Participants grant to DOT and any parties acting on their behalf the right to:

1. Review, screen, and evaluate submitted materials in per the Judging Criteria as detailed below.
2. Describe the Submission in any materials created in connection with this prize competition.

Participant further grants the DOT, and anyone acting on its behalf the right to publicize Participant’s name and, as applicable, the name of Participant’s team members and/or the name of any Entity that assisted in preparing Participant’s submission. Such authority includes posting or linking to the Participant’s submission on DOT websites, including the Challenge website, and inclusion of the Participant’s submission in any other media, worldwide. More specifically, such authority includes the right to copy, distribute, publicly display, and publicly perform all parts of Participant’s submission that would not otherwise be exempt from disclosure under FOIA.

VII. Judging

Stage 1A Judging Criteria

Four judging criteria will be used in Stage 1A. All criteria have approximately the same weight. Only submissions that meet the eligible criteria (see Section VI, *Eligibility*) will be evaluated.

Technical Merit

- The proposed Intersection Safety System (ISS) Concept demonstrates a technically feasible and compelling path to prototype testing and development that:

    - satisfactorily addresses all *Minimum ISS Capabilities* (see Section IV)
    - meets or exceeds all *High-Level ISS Requirements* (see Section IV)
- The proposed concept provides a technically feasible and compelling solution for suitably robust detection, localization, and classification of both vehicles and vulnerable road users in real-time (see Section II*, Vulnerable Road Users*). The proposed classification is sufficiently refined to differentiate sub-categories of vulnerable road users and vehicles relevant to intersection control.
- The proposed ISS concept has a technically feasible and compelling approach to both monitor and anticipate individual vehicle and vulnerable road user path, pace, and progress while in and near the intersection in real-time.
- The ISS Concept Paper identifies the most relevant technical risks associated with the proposed approach and provides viable mechanisms for the avoidance, elimination, or mitigation of these risks with further development.

Deployment Suitability

- The proposed concept (or its component elements) can be readied to initiate physical system prototyping at the time Stage 2 is scheduled to begin -- and potential replication and deployment at scale within ten years.
- The ISS Concept Paper clearly identifies the specific intersection conditions under which the proposed ISS could be cost-effectively deployed. This includes the clear identification of the specific types of intersection geometry/configuration, intersection control system and features, built environment and land-use, vulnerable road user and vehicular demand levels, and any/all assumptions made regarding where the proposed ISS concept could be cost-effectively deployed.
    - Note that a single, comprehensive ISS solution, while desirable, is not required. ISS concepts tailored to specific high-risk intersection types are encouraged if these specific intersection types are suitably prevalent across the nation.
- The ISS Concept Paper provides a sufficiently detailed assessment of projected ISS costs of at-scale deployment (see Section IV). The supporting narrative provides evidence that ISS costs per intersection can be reduced to a level compelling enough to encourage broad nationwide deployment at high-risk intersections.
- The ISS Concept Paper provides a compelling approach to interoperable deployment at scale, including the utilization of existing communication protocols, relevant standards, and a solution for communication and integration among adjacent intersections.

Alignment with Challenge Vision

- The proposed ISS concept is aligned with the vision of the Challenge, namely to:
    - transform intersection safety through the development of one or more innovative intersection safety systems that identify, predict, and mitigate unsafe conditions involving vehicles and vulnerable road users in real-time.

Participant Team Organization and Qualifications

- Team composition and leadership are clearly presented, including a single overall team leader/point-of-contact (including e-mail and phone information). All team members (individuals and organizations) are clearly identified. DOT will communicate with individual participants and participant teams through the single team leader designated.

- Team experience and qualifications with relevant technologies and systems are sufficient to advance the concept through virtual testing successfully. Specifically, team expertise and qualifications are sufficient to:
  - identify, describe, and mitigate ISS technical risk (see *Technical Merit* criterion above), and
  - accurately assess the timeline for prototyping and deployment of the candidate ISS (see *Deployment Suitability* criterion above).

Stage 1B Judging Criteria

Stage 1B judging criteria are expected to be similar to Stage 1A judging criteria. Complete Stage 1B judging criteria will be provided when Stage 1B is initiated.

VIII. How to Enter – Stage 1A

TIP: The system times out after 20 minutes of inactivity, so be sure to click "Save Draft' often to save your work. The submission package consists of a single Concept Paper uploaded to https://www.challenge.gov/?challenge=us-dot-intersection-safety-challenge:

Concept Paper: All submitted materials must be contained in a single PDF file consisting of a maximum of 15 pages and no larger than 8MB in total file size. *Note that the page and file size limit is absolute*.

- Note: The 15-page limit *INCLUDES* any/all materials submitted, including images and diagrams. A cover page, if included, will count against the 15-page limit. Submissions over the 15-page limit will not be accepted and will be ineligible for prizes.
- Note: Submitted materials in excess of 8MB in total file size will not be accepted and will be ineligible for prizes.

There is no required format for this submission, but respondents should carefully consider how their submission addresses the Stage 1A judging criteria (above) and provides all of the information necessary for the evaluation of the concept and the capability of the respondents.

Text in the Concept Paper may be no smaller than 11-point font size with 1" margins. Text in tables or graphics of any font size are acceptable provided they are legible.

Please contact safeintersections@dot.gov if you experience any technical difficulties while submitting your proposal. Emails received after 5:00 PM ET may not receive a response until regular business hours resume.

Enhancing Intersection Safety through Federated Learning on Dynamic Multimodal Data Sets

1 Problem Statement:

The Nashville Metro Area faces challenges in ensuring optimal safety at critical intersections. Current systems lack real-time adaptability, scalability, and data-centric prediction capabilities, increasing vehicle and road user vulnerability. There's an imminent need for an intersection safety software system for four pivotal intersections that employs Federated Machine Learning. This technology can analyze and predict traffic patterns without central data storage, ensuring efficient response while maintaining user privacy. The system must include sensing and perception features to predict vehicle and road user behaviors. Given budget constraints, the cost must not exceed USD 10,000 per intersection.

Furthermore, it should be capable of seamless wireless communications, accurate positioning, and effective interaction with existing intersection control systems. An integrated warning system should alert users of potential hazards. The software must be interoperable, allowing for future integration with emerging technologies and extensible, facilitating scalability. Lastly, an event reporting feature is crucial for continuous performance evaluation, enabling systemic improvements. This solution substantially mitigates intersection-related incidents, protecting the community's well-being while optimizing traffic flow.

2 Summary:

Intersection-related collisions represent a significant and pressing challenge to the safety of our road users, with consequences ranging from minor inconveniences to devastating fatalities. Improving the safety of pedestrians, bicyclists, and other vulnerable road users is of critical importance to achieving the objectives of the U.S. Department of Transportation (DOT) National Roadway Safety Strategy (NRSS) and DOT's vision of zero fatalities and severe injuries across our transportation system. According to data from the National Highway Traffic Safety Administration (NHTSA), 10,626 traffic fatalities occurred at roadway intersections in the United States in 2020, including 1,674 pedestrian and 355 bicyclist fatalities. These fatalities at crossings represent 27% of the 38,824 road traffic deaths recorded in 2020. Preliminary estimates for 2021 point to further increases, with pedestrian fatalities up 13% and pedal-cyclist fatalities up 5% compared to 2020

As cities expand and evolve, the demands on our transportation network also grow, bringing into sharp focus the critical need for innovative, scalable, and efficient safety systems at intersections. Nashville Department of Transportation (NDOT), in collaboration with Tennessee State University (TSU), is motivated by a sincere commitment to improve the lives of our community members, ensuring their safety as they navigate the intricate web of Nashville's roads.

We recognize the enormous potential of cutting-edge technologies to redefine the paradigms of road safety. Our request for this funding stems from an understanding of effectively tackling the prevailing challenges at intersections. We must combine advanced technological solutions with our existing expertise. Resources are pivotal in driving this transformation, and this fund represents a beacon of hope for our community.

With the funds granted, our primary objective is to delve deep into research to conceive, develop, and refine a cost-effective and efficient intersection safety system. Grounded in the principles of federated learning, we envisage a cloud-edge platform for each intersection seamlessly connected to centralized servers. This system will monitor, anticipate, and mitigate unsafe intersection conditions and empower our infrastructure to 'learn' and 'adapt' in real-time.

Our collaborative focus is on enhancing the safety measures at Railroad Highway Grade crossings – a nexus of rail and road where the room for error is minimal. By integrating advanced sensing

mechanisms and predictive analytics, we are working to significantly reduce risks at these crossings, ensuring a smooth and safe passage for both rail and road users.

Securing this funding will be transformative for our current research trajectory. While our endeavors in Railroad Highway Grade crossing safety are gaining momentum, this financial injection would enable us to extend our research boundaries to encompass road intersection safety. Leveraging our insights from railroad intersections, we are poised to unearth novel strategies and technologies that can be applied to road intersections, catalyzing the realization of a holistic, integrated, and adaptive safety system.

Looking ahead, our collaborative ambition stretches beyond the confines of Nashville. Rooted in the bedrock of innovation and community welfare, our overarching research goal is to architect safety systems that are effective and scalable. We envisage a future where our innovations serve as a gold standard, paving the way for nationwide, and potentially even global, adoption. As intersections transform with the ebb and flow of urbanization, our solutions will stand as robust sentinels, ensuring future generations' safety.

In conclusion, our plea for this fund is more than merely soliciting financial assistance. It is an invitation for the U.S. Department of Transportation to partner with us in crafting a future where every intersection, regardless of its complexity or location, is a haven of safety. With the confluence of resources, expertise, and vision, we can chart a course to a safer, more intelligent, and more connected transportation ecosystem for all.

3 Background Research:

Integrating Artificial Intelligence (A.I.) and Machine Learning (ML) technologies in highway junction safety has emerged as a promising frontier for academic research and practical implementation. These advanced technologies offer a plethora of solutions aimed at enhancing the safety, efficiency, and adaptability of roadways to dynamic traffic conditions [1][2][3][4][5][6]. While the potential benefits are significant, applying deep learning techniques in this context presents challenges, most notably the requirement for large datasets and substantial computational resources. These requirements not only escalate the operational costs but also raise concerns regarding data privacy and security [7][8][9]. Previous studies have suggested using a hybrid cloud-edge architecture to address the computational inefficiencies. This architecture balances the data processing load between localized servers, often called the "edge," and a centralized cloud system. However, this approach, while effective in some respects, still incurs a high computational cost and latency, making it less than ideal for real-time applications [10][11][12]. Considering these challenges, the focus of the current research is threefold. First, we aim to significantly reduce the computational time required for model training and inference by eliminating the necessity for data transfer between localized servers and centralized cloud systems. Second, we are committed to enhancing the accuracy of models in real-time implementations, thereby making the system more reliable for immediate decision-making processes. Lastly, we introduce an innovative framework based on intelligent federated learning at the edge-cloud interface. This framework is meticulously designed to tackle the unique challenges of ensuring safety at highway intersections.

4 SYSTEMS MODEL:

4.1 Intersection safety system (ISS) architecture:

The Intersection Safety System (ISS) needs to predict and prevent potential collisions at intersections by understanding the real-time movements of vehicles and vulnerable road users, especially when they lack wireless connectivity. Implementing federated learning-based A.I. and ML solutions will enable the ISS to analyze local data from various sources efficiently, ensuring timely and adequate warnings for all road users, regardless of their connectivity status. We propose an intelligence AI-driven edge-cloud-based automated system design for providing ISS. Figure 1 depicts the proposed framework.

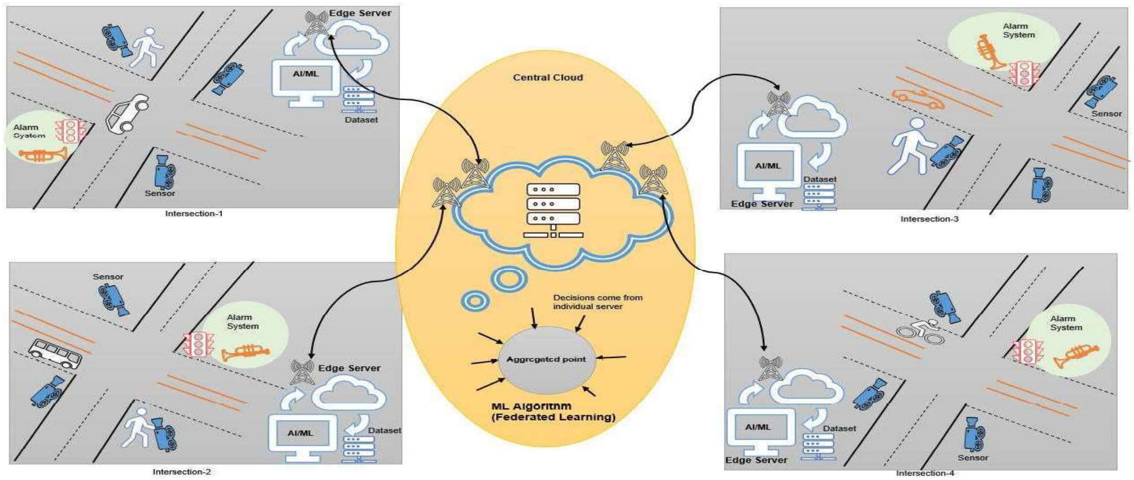


Figure. 1: Proposed AI-driven framework for ISS

4.2 Proposed AI-driven federated learning-based edge-cloud solutions for ISS:

In ML, where data processing demands are high, efficient system design can save costs, especially in cloud-based environments where computational and storage costs can escalate with inefficient structures. Figure 1 represents multiple intersections connected with the principal central server. Each intersection edge server will be incorporated to store the real-time data captured by several sensors (camera, radar, lidar, and infrared) and for real-time decisions made by AI-based federated learning. Federated learning is an ML approach that trains the model across multiple devices or edge servers while keeping the data localized. Instead of sending all the data to a central server for training, federated learning sends the model to the data, allowing each device or server to train the model on its local data. Then, only the model updates (not the data itself) are sent back to a central server, where they are aggregated to improve the global model. This approach prioritizes data privacy and efficiency.

4.3 Federated Learning: A Mathematical Overview for Object Detection and Classification:

Federated Learning (F.L.) is a machine learning approach in which a model is trained across multiple devices or servers while localizing the data. The primary goal is to train shared models without centralizing the data, thus addressing privacy and data security concerns.

Local Training: Each client k trains the model on its local data D_k for E epochs, producing an updated model with parameters θ_k. The local update can be represented as:

$$\theta_k^{t+1} = \theta^t - \eta \nabla L(D_k, \theta^t)$$

Where: $\theta^t$is the model parameter at iteration t, η is the learning rate, L is the loss function, which can be a combination of classification loss and localization loss for object detection task.

Model Aggregation: Clients send their updated model parameters θ_k to the central server. The server aggregates these updates to produce a new global model. A simple aggregation method is the weighted average:

$$\theta^{t+1} = \sum_k w_k \, \theta_k^{t+1}$$

Where W_k is the weight for client k, often operational to the size of the local dataset D_k.

4.4 Implementation of Federated Learning in ISS:
Modern urban intersections are poised to benefit from the integration of edge servers, forming a cohesive network connected to a centralized cloud infrastructure. In the proposed framework:

- A.I. algorithms are strategically deployed at each intersection on the respective edge servers, which house the local data pertinent to that intersection.
- These algorithms are tailored to learn autonomously, adapting to their specific intersections' unique traffic patterns and conditions. This results in diverse data-driven models that capture the nuances of different intersections.
- Periodically, post-processing, each intersection's model refines its feature extraction techniques by leveraging datasets from other intersections, enhancing its predictive capabilities.
- Subsequently, these refined algorithms transmit only their enhanced feature extraction methodologies to a central aggregation point within the cloud server, ensuring data privacy.
- After assimilating insights from all intersections, the central server broadcasts a comprehensive and robust model back to each intersection. This model is equipped to make informed decisions, particularly concerning the safety of vulnerable road users.

Central to this framework is the principle of federated learning. It ensures that while devices continuously learn and adapt from local data, the raw data remains confined to its original location, and only the distilled knowledge (akin to refined feature extraction techniques) is centrally shared and aggregated.

4.5 Optimizing Intersection Safety: A Cost-Effective and Time-Efficient Federated Learning Approach in Edge-Cloud Infrastructure:

Integrating federated learning within edge-cloud infrastructure offers a novel approach to optimize intersection safety, addressing real-time responsiveness and data privacy concerns. By decentralizing the training process across edge servers at individual intersections, computational demands on a central server are significantly reduced, leading to cost savings. The localized data processing at the source, through edge servers, ensures timely decision-making, which is crucial for preventing potential collisions and ensuring road user safety. The overarching architecture minimizes data transfer costs and accelerates the model training process, as data doesn't need to be sent back and forth between central and local servers. This innovative approach combines the strengths of both edge computing and federated learning, paving the way for a more efficient and cost-effective solution to enhance intersection safety.

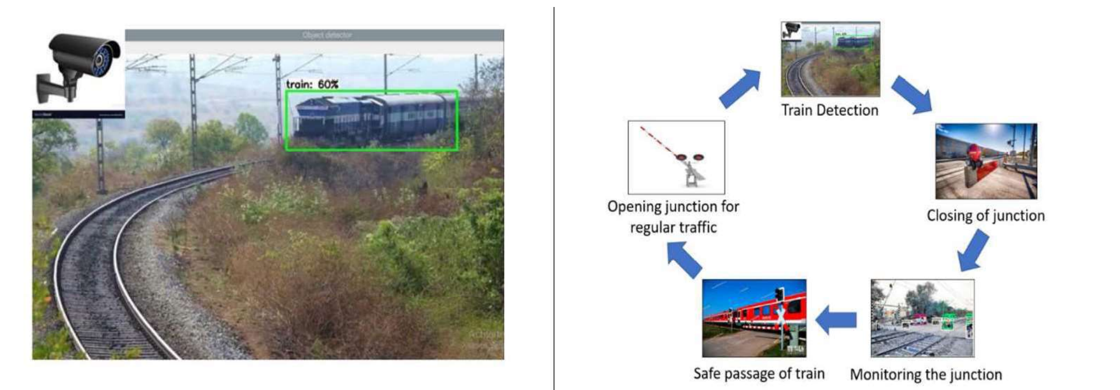
4.6 The action of alarm system in intersection safety:

When the A.I. model finds a potential danger in the intersection, they raise their stop sign to halt traffic. In the same way, the ISS can change traffic lights or send out warnings to prevent accidents. If the vulnerable road user doesn't notice the guard's stop sign, the guard might shout or whistle to get their attention. Similarly, ISS has ways to alert vehicles and people, even if they don't have special devices to receive warnings. The ISS acts like a super-smart crossing guard on duty, ensuring everyone crosses the intersection safely. Figure 1 also shows the alarm system at each intersection.

5 PRELIMINARY WORK:

5.1 Recent research Progress for Railroad Highway Grade crossing safety (RHGC):

Our latest study gathered specialized video footage (Figure 2) from various grade-level crossings featuring pedestrians, automobiles, buses, lorries, and bikes. This data was then processed using a unique edge-cloud-based WBS ensemble model optimized for machine learning. The algorithms were trained and validated on high-performance computing systems within the engineering laboratory at Tennessee State University. We propose an infrastructure incorporating an edge-cloud architecture, with object recognition and segmentation models situated on the edge server at the grade crossing. This server is linked to monitoring cameras, enabling immediate, on-site data analysis. This configuration reduces latency and optimizes network bandwidth by transmitting only crucial, processed data to the centralized cloud. The system architecture seamlessly integrates cloud and edge computing capabilities. Advanced A.I. and machine learning technologies underpin the object detection and segmentation algorithms, enhancing the system's overall responsiveness. To augment our research further, we are exploring federated learning approaches to reduce computational time and improve algorithmic accuracy, thereby eliminating the need for data transfer from local to central servers.



Train Detection at level crossing	Stages involved in an automated level crossing.

Figure 2: Sample AI and ML Application for automated level-crossing to detect the oncoming train.

5.2 RHGC model architecture:

In our study on RHGC object detection, we developed a novel strategy known as weighted-based fusion (WBF) to address the limitations of the non-maximum suppression (NMS) method. We submitted a high-quality publication for review at the annual Transportation Research Board (TRB) meeting in 2024. With the NMS method, bounding boxes presume to pertain to a solitary object when their intersection over union (IoU) exceeds a certain pre-established threshold. Thus, the box filtering process depends on selecting this single IoU threshold value, which affects the model's performance. Setting this threshold is complex; one might lose if objects are close together. NMS removes extra boxes and struggles to create averaged predictions from different models. The critical difference between NMS and WBF is that WBF uses all the boxes, not just some. NMS removes extra boxes, but WBF makes a new box (a fused box) using all the prediction boxes. Our proposed WBF ensemble model combines YOLOv8m, YOLOv8l, and YOLOv8x. YOLOv8 models outperform previous YOLO versions, including YOLOv5 and YOLOv7.

Moreover, compared with YOLO models trained on 640 image resolution, all the YOLOv8 models exhibit improved throughput while maintaining a similar parameter count. In our research for RHGC object detection, the efficacy and advancements demonstrated by the YOLOv8 models have proven highly promising and influential. The primary objective of ensemble models is to minimize the generalization error of predictions. Figure 3 represents the WBS-based ensemble model.

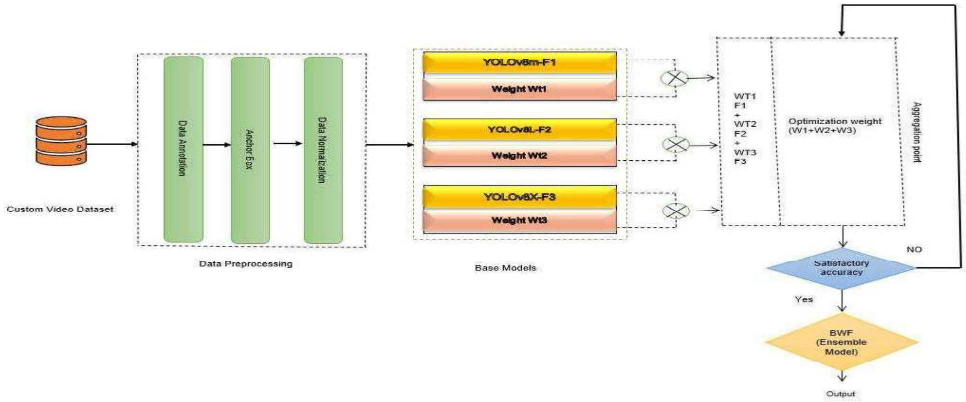


Figure. 3 represents the WBS-based ensemble model architecture.

5.3 Preliminary Model Result Analysis:

Our research evaluates the WBF ensemble model's RHGC safety performance utilizing several traditional ML criteria, including confusion matrix, precision-recall curve, training and validation loss, and accuracy. Figure 4 demonstrates the model's true positive, true negative, false positive, and false negative rates in the confusion matrix. The model has excellent actual favorable rates of 95% % and 100% for the car and people classes, respectively, with a car class false positive rate of 0.05%. The overall model accuracy is 97%. Figure 5 depicts the precision-recall curve, a crucial parameter for evaluating models in class imbalance situations. It shows the precision-recall trade-off. Figure 6 shows the training and validation loss and accuracy curves, measuring model performance, identifying overfitting and underfitting, optimizing hyperparameters, monitoring training progress, and comparing models. Losses decreasing with time suggest the model optimally. Extensive testing in RHGC safety applications substantiates the validity and reliability of our proposed models.

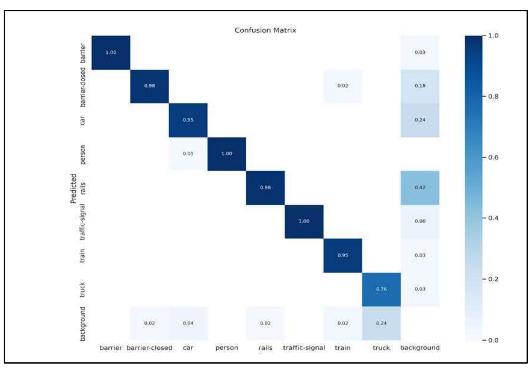


Figure 4: Confusion Matrix

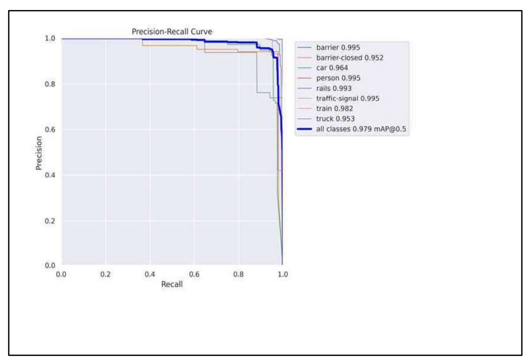


Figure 5: ROC Curve

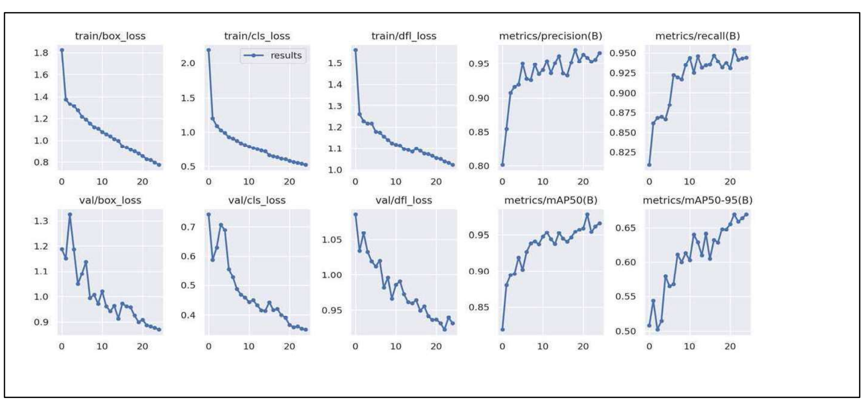


Figure 6: Training and Validation loss and accuracy

6 PROJECT MANAGEMENT PLAN

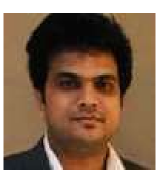
6.1 Project Schedule

Task	Description	Q1	Q2	Q3	Q4
Project Initiation	- Define project objectives and goals.				
	- Identify stakeholders and create a stakeholder communication plan.				
	- Form a project team.				
Research and Analysis	- Conduct research on the intersection safety problem.				
	- Analyze existing data and solutions.				
	- Identify key challenges and opportunities.				
Requirements Gathering	- Define specific requirements for the solution or proposal.				
	- Engage with subject matter experts to gather insights.				
Equipment Procurement and Installation					
Developing software systems for intersection safety	- Create a design or concept for the proposed solution.				
	- Develop technical specifications.				
	- Consider user experience and interface design.				
Prototyping and Development	- Build a prototype or develop the proposed solution.				
	- Test and iterate on the solution as necessary.				
Implementing the software systems in four intersection					
Validation of the system and correction and implement.	- Conduct thorough testing				
Final report and lesson learning delivery					

7 Participant Team Organization and Qualifications

The long-term success of this project will occur in conjunction with the input from NDOT and TSU.

TSU will do the applied research on federated learning-based intersection safety. NDOT will provide the implementation support selection of four intersections for this pilot implementation around the Nashville metro area. The cross-institute project management team comprises Murad Al Qurishee from NDOT as a project investigator (PI), his team, and Kamrul Hasan, Ph.D. from TSU, as a PI and his team.



Dr. Kamrul Hasan is an Assistant Professor of Electrical and Computer Engineering at TSU. His research interest includes AI and ML-enabled autonomous model development, Physics Informed Deep Learning (PIDL) model development and verification for Transportation Engineering, AI/ ML-enabled cyber risk detection, and mitigation tools development. Since 2020, he has worked as P.I./Co-PI for four research projects funded by the National Science Foundation (NSF), the Electric Power Research Institute (EPRI), and FRA. He authored over 20 peer-reviewed high-impact papers, one book chapter, and one U.S. patent.

Murad Al Qurishee is a highly qualified NDOT's engineer with a Master's in Civil Engineering from the University of Tennessee and a Bachelor's from Chittagong University. His experience includes key roles in traffic management and intelligent transportation systems, managing various projects, overseeing ITS deployment, and ensuring regulatory compliance. Murad is a licensed Professional Engineer and holds several certifications. He has authored multiple research papers and made conference presentations, showcasing his expertise in deep learning and UAV technology for infrastructure assessment. He managed both Federal Grants and State Grants such as CMAQ, ATCMTD, SMART, I-24 ICM corridor, etc. Overall, Murad's diverse skills and accomplishments make him a valuable asset for this project.

8 Budget

Task	Budget Allocation
Project Initiation	USD 10,000
Research, Analysis, and Prototype development	USD 55000
Graduate Student's Stipend and Tuition for One year	USD 35,000
Total Budget Allocation	USD 100,000

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[12] M. Jiang, T. Wu, Z. Wang, Y. Gong, L. Zhang, and R. P. Liu, "A Multi-Intersection Vehicular Cooperative Control Based on End-Edge-Cloud Computing," *IEEE Trans. Veh. Technol.*, vol. 71, no. 3, pp. 2459–2471, 2022, doi: 10.1109/TVT.2022.3143828.

APPLICATION FOR U.S DOT Intersection Safety Challenge

METROPOLITAN GOVERNMENT OF NASHVILLE AND DAVIDSON COUNTY

DocuSigned by:
Diana W. Alarcon
CCA6046554B9461...

9/19/2023

Diana W. Alarcon, Director
Department of Transportation and
Multimodal Infrastructure

Date

GRANT APPLICATION SUMMARY SHEET

Grant Name: U.S. DOT Intersection Safety Challenge 24-26

Department: NDOT

Grantor: U.S. DEPARTMENT OF TRANSPORTATION

Pass-Through Grantor (If applicable):

Total Applied For $100,000.00

Metro Cash Match: $0.00

Department Contact: Casey Hopkins
8801676

Status: NEW

Program Description:

The Nashville Metro Area faces challenges in ensuring optimal safety at critical intersections. Current systems lack real-time adaptability, scalability, and data-centric prediction capabilities, increasing vehicle and road user vulnerability. There's an imminent need for an intersection safety software system for four pivotal intersections that employs Federated Machine Learning. This technology can analyze and predict traffic patterns without central data storage, ensuring efficient response while maintaining user privacy. The system must include sensing and perception features to predict vehicle and road user behaviors.

Plan for continuation of services upon grant expiration:

Apply for phase 2 of the Challenge if the data collected determines a need.

APPROVED AS TO AVAILABILITY OF FUNDS:

Kelly Flannery/mjw 9/25/2023 | 8:11 AM CDT

Director of Finance RW AP **Date**

APPROVED AS TO FORM AND LEGALITY:

Courtney Mohan 9/25/2023 | 11:09 AM

Metropolitan Attorney **Date**

APPROVED AS TO RISK AND INSURANCE:

Balogun Cobb 9/25/2023 | 8:18 AM CDT

Director of Risk Management Services **Date**

Freddie O'Connell 9/25/2023 | 1:09 PM

Metropolitan Mayor **Date** kW

(This application is contingent upon approval of the application by the Metropolitan Council.)

Grants Tracking Form

Part One

Pre-Application ◉ Application ○ Award Acceptance ○ Contract Amendment ○

Department	Dept. No.	Contact	Phone	Fax
NDOT	042	Casey Hopkins	8801676	

Grant Name:	U.S. DOT Intersection Safety Challenge 24-26
Grantor:	U.S. DEPARTMENT OF TRANSPORTATION
Other:	
Grant Period From:	01/01/24
Grant Period To:	01/01/26
(applications only) **Anticipated Application Date:**	09/22/23
(applications only) **Application Deadline:**	09/25/23
Funding Type:	FED DIRECT
Pass-Thru:	Select Pass-Thru --- >
Award Type:	COMPETITIVE
Status:	NEW
Metro Category:	New Initiative
CFDA #	
Multi-Department Grant	☐ → If yes, list below.
Outside Consultant Project:	☐
Total Award:	$100,000.00
Metro Cash Match:	$0.00
Metro In-Kind Match:	$0.00
Is Council approval required?	☑
Applic. Submitted Electronically?	☑

Project Description:

The Nashville Metro Area faces challenges in ensuring optimal safety at critical intersections. Current systems lack real-time adaptability, scalability, and data-centric prediction capabilities, increasing vehicle and road user vulnerability. There's an imminent need for an intersection safety software system for four pivotal intersections that employs Federated Machine Learning. This technology can analyze and predict traffic patterns without central data storage, ensuring efficient response while maintaining user privacy. The system must include sensing and perception features to predict vehicle and road user behaviors.

Plan for continuation of service after expiration of grant/Budgetary Impact:

Apply for phase 2 of the Challenge if the data collected determines a need.

How is Match Determined?

Fixed Amount of $ ______ or ______ **% of Grant** ______ **Other:** ☐

Explanation for "Other" means of determining match:

For this Metro FY, how much of the required local Metro cash match:

Is already in department budget?	$0.00	**Fund**	N/A	**Business Unit**	N/A
Is not budgeted?	$0.00	**Proposed Source of Match:**			N/A

(Indicate Match Amount & Source for Remaining Grant Years in Budget Below)

Other:

Number of FTEs the grant will fund:	0.00	**Actual number of positions added:**	0.00	
Departmental Indirect Cost Rate	18.83%	**Indirect Cost of Grant to Metro:**	$18,830.00	
***Indirect Costs allowed?** ○ Yes ◉ No **% Allow.**	0.00%	**Ind. Cost Requested from Grantor:**	$0.00	**in budget**

***(If "No", please attach documentation from the grantor that indirect costs are not allowable. See Instructions)**

Draw down allowable? ☐

Metro or Community-based Partners:

Tennessee State University

Part Two

Grant Budget

Budget Year	Metro Fiscal Year	Federal Grantor	State Grantor	Other Grantor	Local Match Cash	Match Source (Fund, BU)	Local Match In-Kind	Total Grant Each Year	Indirect Cost to Metro	Ind. Cost Neg. from Grantor
Yr 1	FY24	$100,000.00	$0.00	$0.00	$0.00	N/A	$0.00	$0.00	$18,830.00	$0.00
Yr 2	FY__									
Yr 3	FY__									
Yr 4	FY__									
Yr 5	FY__									
Total		$100,000.00	$0.00	$0.00	$0.00		$0.00	$0.00	$18,830.00	$0.00

Date Awarded:		**Tot. Awarded:**		**Contract#:**	
(or) **Date Denied:**		**Reason:**			
(or) **Date Withdrawn:**		**Reason:**			

Contact: juanita.paulsen@nashville.gov
vaughn.wilson@nashville.gov

Rev. 5/13/13

5705

GCP Rec'd
09/21/23

GCP Approved
09/21/23

VW

U.S. DOT Intersection Safety Challenge: Stage 1A (Concept Paper) Prize Competition Description for Participants

Contents

Version	Publication Date	Description of Changes
Original	4/25/2023	N/A
Revision 1	7/26/2023	Figure 1 – months revised. Table 1 – dates revised.

Note: *This document constitutes the complete official terms and conditions for Stage 1A (Concept Paper) Prize Competition of the U.S. DOT Intersection Safety Challenge. U.S. DOT reserves the right, in its sole discretion, to (a) cancel, suspend, or modify the Challenge, and (b) not award any prizes if no entries are deemed worthy. Any modifications to Stage 1A of the U.S. DOT Intersection Safety Challenge will be reflected in this document.*

I. Summary

Improving the safety of pedestrians, bicyclists, and other vulnerable road users is of critical importance to achieving the objectives of the U.S. Department of Transportation (DOT) National Roadway Safety Strategy (NRSS) and DOT's vision of zero fatalities and serious injuries across our transportation system. According to data from the National Highway Traffic Safety Administration (NHTSA), 10,626 traffic fatalities occurred at roadway intersections in the United States in 2020, including 1,674 pedestrian and 355 bicyclist fatalities. These fatalities at intersections represent 27% of the total of 38,824 road traffic deaths recorded in 2020. Preliminary estimates for 2021 point to further increases, with pedestrian fatalities up 13% and pedalcyclist fatalities up 5% compared to 2020 (NHTSA, May 2022).

In response to these growing concerns and as part of DOT's continued implementation of the NRSS, the DOT Intersection Safety Challenge (hereafter, "the Challenge") aims to transform intersection safety by incentivizing the innovative application of new and emerging technologies to identify and mitigate unsafe conditions involving vehicles and vulnerable road users at intersections. The Challenge complements other Federal efforts to improve intersection safety, with the Challenge specifically focused on the use of technology. Further, the intersection environment itself is well-suited to innovative mitigative approaches leveraging, utilizing, and potentially repurposing existing traffic control and support infrastructure.

Of particular interest in addressing intersection safety is the development of systems that apply emerging capabilities enabled by advanced sensing, communications technologies, and artificial intelligence (AI) and machine learning (ML). These include machine sensing and perception, data fusion, trajectory and path prediction, vehicle-to-everything (V2X) communications, and real-time decision-making. Technological advancements in these and other areas offer an opportunity to improve intersection safety at scale in new and effective ways. The Challenge encourages the formation of non-traditional teams combining expertise in emerging technologies with experience in traffic and safety engineering to develop new and potentially transformative intersection safety approaches.

The Challenge also aligns with equity-related DOT priorities set forth in the Bipartisan Infrastructure Law (BIL). Improving intersection safety is a foundational element in enhancing equity and accessibility in many communities. Safe and reliable transportation, including access to and use of various transportation modes in and around intersections, can be a powerful engine of opportunity, connecting people to jobs, education, and resources. The Challenge supports DOT's equity priorities, as outlined in the *U.S. DOT Strategic Plan for FY 2022-2026*, the *U.S. DOT Equity Action* Plan, and the *National Roadway Safety Strategy*.

Overall, the Challenge aims to incentivize the development of new, cost-effective, real-time roadway Intersection Safety System (ISS) concepts (see Section IV). Further, to set the stage for future deployment nationwide, the potential safety benefits relative to the estimated costs of deploying new system concepts must be compelling enough to motivate equitable at-scale deployment across the nation.

II. Background

The Challenge seeks to incentivize the development of transformative, innovative intersection safety systems employing existing and emerging technologies. Many modern control systems, including emerging advanced intersection control systems, are increasingly reliant on real-time decision-making informed by data ingested and analyzed from advanced sensor systems. This includes safety-critical machine decision-making where human response times may be insufficiently rapid or lack comprehensive situational awareness. Often, powerful new control systems combine the strengths of both human and machine decision-making. One relevant example of mixed human/machine control is in vehicle automation. Here, the confluence of developments in sensing, data fusion, and AI are creating new and compelling Advanced Driver Assistance Systems (ADAS) and emerging Automated Driving Systems (ADS). Such systems may issue warnings to a human driver or independently implement safety-critical vehicle control decisions.

Anticipation, Prevention, and Mitigation of Unsafe Intersection Conditions

DOT is interested in the development of new safety systems that adapt salient emerging technologies to enhance real-time traffic and pedestrian control systems and support road user warning systems. Such safety systems are expected to anticipate, prevent, and mitigate unsafe intersection conditions, including impending collisions among and between vehicles and vulnerable road users.

Anticipation, prevention, and mitigation of unsafe conditions may take place on multiple time scales relevant to the safety-related control decisions under consideration, including imminent collisions in the intersection. Preventive or mitigating decisions and actions may be tailored based on the real-time (or anticipated) pedestrian, bike, and vehicle patterns of travel in the intersection. For example, in anticipation of a surge in pedestrian demand in one or more crosswalks, intersection control systems could dynamically implement or prohibit unprotected vehicular intersection movements where appropriate vehicle control indicators are present. These changes could be made in combination with complementary modifications to pedestrian and/or bike lane traffic control (e.g., extended stop or walk time for specific crosswalks). Modifications to control systems may be augmented with warning systems alerting vulnerable road users and/or drivers. Additional tailored warnings may be transmitted for wirelessly connected vehicles and mobile devices able to interpret and act on standardized safety-related messages. Finally, detailed data on categorized road user demand (including individual vehicle trajectory and/or user paths through and around an intersection) could inform longer-term decisions regarding the intersection safety, including the installation of (or upgrade to) more capable traffic control systems, geometric changes, and/or the modification of local safety-related policies.

Vulnerable Road Users

The Challenge utilizes the definition of a “vulnerable road user” consistent with the Highway Safety Improvement Program: a non-motorist with a fatality analysis reporting system (FARS) person attribute code for pedestrian, bicyclist, other cyclist, and person on personal conveyance as defined in the ANSI D16.1-2007. (*Se* 23 U.S.C. 148(a)(15); 23 CFR 490.205). Under this definition, a vulnerable road user may include people walking, biking, or rolling but does not include a motorcyclist. Note that this definition of a vulnerable road user is specific for this Challenge. DOT considers a broader definition in some studies and/or countermeasure development depending on the circumstances.

For the Challenge, *vulnerable road users* are defined in accordance with this definition as pedestrians, cyclists, and most micro-mobility device users, including users of wheelchairs, scooters, skateboards, and other conveyances, of all ages and abilities. Likewise, for the Challenge, *vehicles* are defined as all motorized roadway vehicles including passenger cars, motorcycles, trucks, vans, public transit vehicles (including buses, light rail vehicles, and streetcars), and commercial vehicles. E-bikes and other micro-mobility conveyances capable of operating above 30 miles per hour are treated as motorcycles.

Whatever the general road user type, a critical differentiator is the class of intersection control assigned to an individual road user in an intersection at any point in time. For example, cyclists are vulnerable road users but are subject to vehicular traffic control when they travel in general roadway lanes. In a bike lane, a cyclist may be subject to bike-specific controls and policies that differ from general roadway lanes. Further, where bike lanes are present, e-bikes up to a certain size or power may utilize these lanes subject to local policy and regulations, and in this case may also be subject to bike-specific controls and policies. Generally, bikes are not allowed on sidewalks unless the cyclist dismounts. A dismounted cyclist pushing a bike is subject to pedestrian controls and may utilize crosswalks. Likewise, low-speed motorized scooters allowed under local policy to utilize sidewalks are subject to pedestrian control indicators, signage, and regulations.

In this Challenge, DOT is interested in enhancing holistic intersection safety including within roadway lanes, bike lanes, crosswalks, and sidewalks. In particular, the Challenge seeks specific system solutions that can detect and classify a comprehensive range of road users in real-time and detect or anticipate their individual movements in or across an intersection over time. This desired capability explicitly includes the transition of a single individual subject from one form of intersection control to another, e.g., a dismounted cyclist on a sidewalk mounting a bicycle, entering a bike lane, and then traversing an intersection. The envisioned capabilities must also perform equally across a range of vulnerable road user physical characteristics, including race/ethnicity, gender, age, clothing, size, and the use of adaptive equipment like wheelchairs, mobility scooters, and service animals.

Intersection Safety Improvement at Scale

To improve intersection safety at a national scale, cost-effective safety systems are needed that can ultimately be suitable for broader, nationwide deployment. DOT recognizes that a technology-based approach is one of many potentially cost-effective approaches for improving safety at intersections. Cost-effective approaches are also critical to support equity and accessibility considerations, in that deployment, operations, and maintenance requirements must be low enough to be applied broadly across the nation’s communities. The innovations sought in the Challenge operating in a real-time context are intended to augment (but not substitute for) a comprehensive suite of intersection safety considerations, including alternative intersection geometric design and changes to local traffic safety regulations and policies. The Challenge aligns with the NRSS and complements current and existing DOT safety efforts, such as the FHWA Complete Streets Program and FHWA Proven Safety Countermeasures.

To better understand the technologies that could enhance intersection safety, the DOT published the *Enhancing the Safety of Vulnerable Road Users at Intersections; Request for Information* (RFI) in the

Federal Register (commenting closed on November 15, 2022). Specifically, the RFI sought information on a conceptual vulnerable road user and vehicle warning system building on existing and emerging vehicle automation technologies that could be implemented at intersections. Such an intersection safety system concept might incorporate machine vision, perception, sensor fusion, real-time decision-making, AI, and V2X communications (among other possible approaches). The RFI responses pointed to a wide range of both existing and emerging technologies that could be integrated into intersection safety systems in the near-term.

III. Challenge Vision, Objectives, and Structure

Challenge Vision and Objectives. The vision of the Challenge is to *transform intersection safety through the development of one or more innovative intersection safety systems that identify, predict, and mitigate unsafe conditions involving vehicles and vulnerable road users in real-time*.

The Challenge seeks broad innovation in real-time roadway intersection and transit right of way safety featuring anticipatory warning systems and other safety-countermeasures for both drivers and vulnerable road users. Such intersection safety systems must be cost-effective in order to expedite their equitable deployment at scale at the highest risk intersections throughout the nation. In addition to technical considerations, successful systems must also consider a range of additional factors related to their suitability for at-scale deployment, including commercialization and mass-production feasibility, as well as factors related to the needs and constraints of both industry and Infrastructure Owners and Operators (IOOs).

Challenge Structure. DOT anticipates an overall Challenge structure and timing similar to the one illustrated in **Figure 1** below. (Note: The structure and timing presented is preliminary in nature and subject to change at any time at the sole discretion of the DOT.)

The Challenge begins with a two-part prize competition. Participants can include individuals, organizations, or teams of individuals and organizations, in accordance with the eligibility criteria below. While not a requirement for participation, teaming is encouraged to ensure that the participants possess the wide range of interdisciplinary skills required to ultimately produce a viable intersection safety system. Teams are encouraged further to consider system requirements unique to field deployment (as specified or recommended by IOOs) early in the system development process. In the first part of the prize competition (Stage 1A), participants submit a Concept Paper describing their intersection safety system concept and the potential of this concept to address the vision and objectives of the Challenge. Up to ten (10) awards will be made in Stage 1A to participants whose submissions demonstrate a comprehensive understanding of the problem and who propose a compelling and innovative solution to the safety problem posed.

In Stage 1B, participants will test their proposed system using real world sensor data collected on a closed course to assess the solution's potential to enhance intersection safety. At a minimum, winners from the first part (Stage 1A) will be eligible to participate in the second part (Stage 1B) of the Challenge. Depending on the results achieved during Stage 1A, DOT may choose to broaden Stage 1B eligibility. At the end of Stage 1B, if sufficiently compelling and innovative candidate intersection safety systems are identified, DOT may choose to fund follow-on projects in a second stage. These projects would involve prototyping and demonstration of candidate intersection safety systems under a competitive Broad Agency Announcement (BAA) or other procurement mechanism.

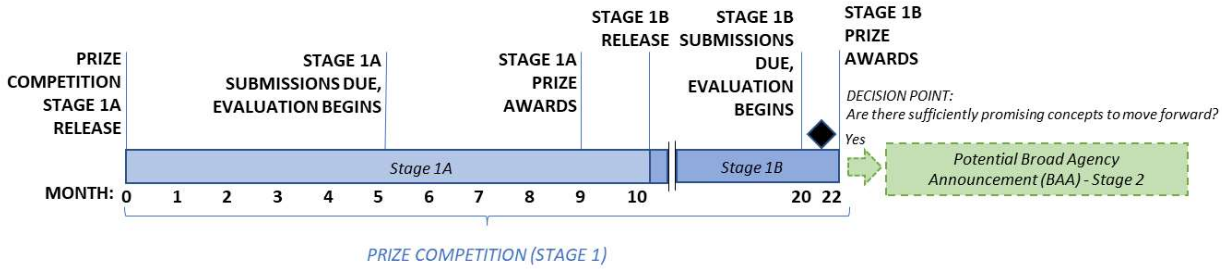


Figure 1. DOT Intersection Safety Challenge Structure and Schedule (Preliminary)

DOT Intersection Safety Challenge Stage 1: Prize Competition

Stage 1A: Concept Assessment — Participants submit an ISS Concept Paper (See Section VIII, *How to Enter*). Up to ten (10) well-formed, differentiable concepts scoring highest against a set of uniform judging criteria (see Section VI and VII, *Rules* and *Judging*, respectively) will receive a Challenge prize and may advance to the next part of the Stage 1 Prize Competition.

Stage 1B: System Assessment and Virtual Testing. Participants develop, train, and improve algorithms for the detection, localization, and classification of vulnerable road users and vehicles using DOT-supplied sensor data collected at a controlled test intersection. Further, participants will use these data and algorithms in real-time to predict future intersection conditions and identify potentially unsafe conditions and events. Entries will be scored using a rubric testing the accuracy of algorithms against observed ground truth conditions. DOT will provide information regarding the perception and prediction competition of Stage 1B after Stage 1A awards are made.

In addition, Stage 1B participants may also submit an ISS Concept Paper (as in Stage 1A). This may be a revised concept paper reflecting insights gained in participation in this prize competition.

Multiple Stage 1B submissions may receive a Challenge prize. Detailed rules and judging criteria will be provided prior to the start of Stage 1B.

Note: Participants are not required to demonstrate ISS deployments within real-world intersections in either Stage 1A or Stage 1B.

Anticipated Schedule: DOT anticipates that Stage 1 of the Challenge will proceed according to the tentative schedule outlined below (Table 1). Dates are subject to change with any changes being posted on the DOT's Challenge website accordingly.

Table 1. Outline of Challenge Schedule (subject to change)

Stage	Description	Date
1A	Launch	Late April 2023
1A	Close	September 2023
1A	Selection and Awards	December 2023 – January 2024
1B	Launch	January 2024 – February 2024

Stage	Description	Date
1B	Close	December 2024
1B	Selection and Awards	February 2025

DOT Intersection Safety Challenge Stage 2: Potential Broad Agency Announcement (BAA) Solicitation (optional)

Informed by the technical maturity of the intersection safety solutions offered in the Stage 1 prize competition and their potential to result in transformative safety impacts, DOT will determine whether to proceed to a second stage of the Challenge. In this potential second stage, DOT may issue a Broad Agency Announcement (BAA) solicitation (open to any eligible entities, whether or not an entity was a Stage 1 participant) to develop, test, and demonstrate one or more prototype ISS. Other procurement mechanisms besides a BAA may also be considered for Stage 2.

IV. The Intersection Safety System (ISS) Concept

Conceptually, an ISS would be deployed at a roadway intersection to modify or adapt intersection controls dynamically and warn drivers and vulnerable road users of potential impending collisions and/or conflicts. **Figure 2** presents a high-level overview of the anticipated elements of an ISS concept. Note that the ISS System of Interest (SOI) is identified as a shaded area in Figure 2, separate from the road users and other intersection infrastructure outside the boundaries of the ISS. Note further that this is a *conceptual* system, and as such is not intended to be prescriptive or represent a complete design.

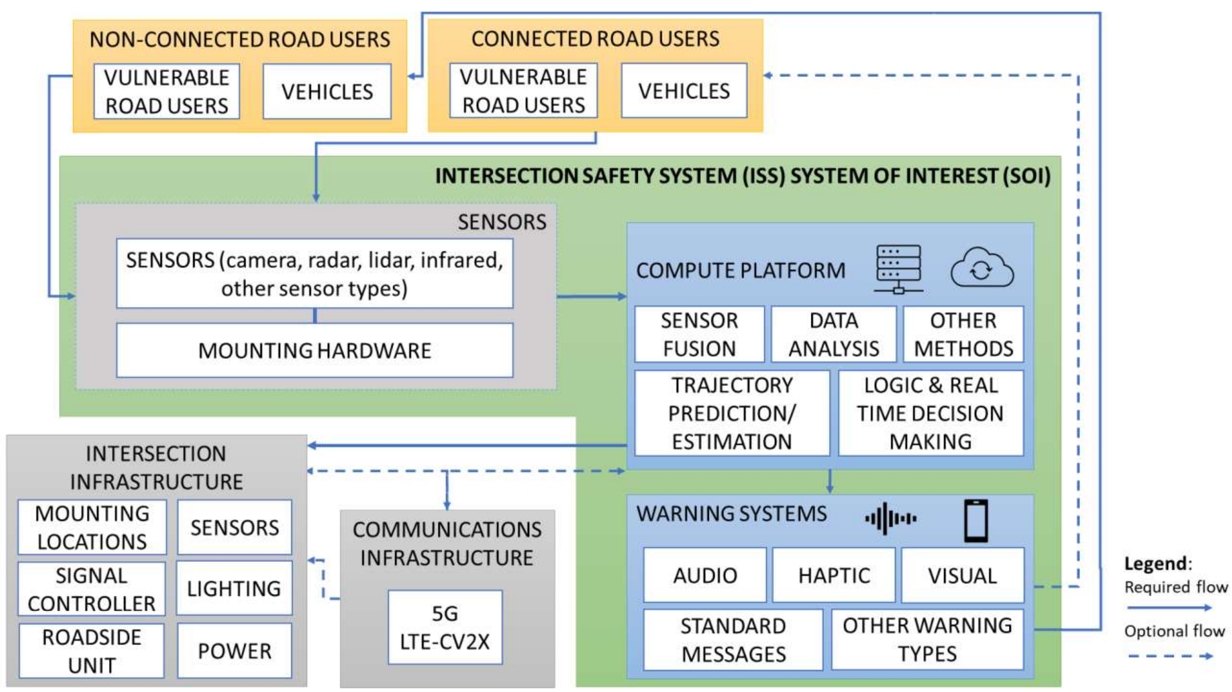


Figure 2. Conceptual Intersection Safety System Context Diagram

The ISS integrates and analyzes sensor data in real-time on a computing platform that hosts the required software elements and machine learning algorithms. The ISS ingests and analyzes sensor data to differentiate, classify, and localize individual vehicles and vulnerable road users in real-time. Further, the ISS predicts the real-time movements and future trajectories of individual vehicles and vulnerable road users within and in the immediate vicinity of the intersection (e.g., on adjacent sidewalks) and transit right of way. As mentioned above, these vehicle movements will include activities specific to transit vehicles and commercial vehicles. The ISS then issues coordinated messages to adapt or modify intersection control configurations in real-time in advance of potentially unsafe conditions and/or generate warnings regarding potential imminent collisions. An ISS must be capable of issuing warnings to drivers and vulnerable road users with no wireless connectivity. Warnings may be issued to wirelessly connected vehicles and vulnerable road users as well. Whether through wireless transmission of alerts or other methods, innovative approaches are sought to ensure that drivers and vulnerable road users can be alerted in an effective and timely way to prevent or mitigate unsafe conditions.

Participants in this Challenge will be asked to consider a range of relevant technologies, assess the potential for re-purposing both existing and emerging technologies to create an ISS concept aligned with the ultimate goal of at-scale deployment within, at most, 10 years. In particular, the Challenge seeks solutions with the potential to be cost-effectively deployed across the nation at a large proportion of the highest-risk intersections. The use of commercially available sensors and associated mass-produced componentry (for computation, networking, connectivity, and communication) may result in lower system costs when deployed at scale.

Intersection Safety System Costs. As an overarching goal, the Challenge seeks ISS solutions that utilize core componentry costing in the order of $10,000 (or less) per intersection at scale within 10 years following the end of the competition. *At scale* in this instance refers to targeted deployments in the order of 100,000 intersections nationwide. Note: The target cost figure pertains only to the cost of ISS-specific hardware and software for the SOI elements shown in Figure 2. Costs associated with the existing intersection geometrics, traffic control systems, power, communications backhaul, and other considerations outside the SOI in Figure 2 are ***excluded*** from this cost target. Further, all other ISS development, deployment, and operational costs, including but not limited to research and development amortization, installation, calibration, testing, training, operations, maintenance, and replacement are ***excluded*** from this cost target.

ISS Deployment Scope. A single ISS concept may not be suitable for implementation at all roadway intersections. The Challenge seeks one or more interoperable ISS solutions that can collectively address a large proportion of our nation's intersections and make a significant improvement in overall road safety. Note that an ISS concept that is intended only for intersections with specific characteristics or which addresses a specific intersection safety use case *may* be submitted for this Challenge. Other ISS concepts may target a broader deployment footprint and a wider range of use cases.

Minimum ISS Capabilities. An ISS should (at a minimum) have the following capabilities:

- Sensing and perception – The ISS must support the detection, localization, and classification of a number of individual vehicles and vulnerable road users simultaneously in real-time, while maintaining privacy protections. Sensing and perception of vulnerable road users must perform equally across skin tones, clothing, and other physical characteristics. An ISS perception system should sense intersection activity under a range of weather and visibility conditions. This includes variable ambient lighting, temperature, precipitation, visibility, glare, and other considerations that may impact sensing and perception. This capability may necessitate the utilization of diverse and/or redundant systems for higher reliability. The resolution, bandwidth, latency, power consumption, and cost of the vision and perception system are important considerations. Precise timing (derived from global navigation satellite systems [GNSS] or secondary or back-up sources that can be space- or land-based) may be employed.

- Vehicle and road user movement prediction – The ISS must predict the movements or trajectories of multiple vehicles and vulnerable road users in and near the intersection in real-time. Simultaneous road user and vehicle movements must be predicted contemporaneously to identify potential unsafe conditions or impending conflicts or collisions. The ISS shall detect potential collisions or other unsafe conditions and plan feasible mitigating actions that reflect a number of common intersection scenarios. Scenarios should be considered where road users both conform to intersection control direction (e.g., a pedestrian who waits to enter a crosswalk until a WALK signal is given), as well as cases where road users deviate (e.g., a pedestrian entering a crosswalk before a WALK signal is given).
- Data handling and storage – The ISS must be capable of managing the volume, bandwidth and variety of data required to enable all minimum capabilities. This includes event reporting covered below. This also includes data storage and archiving requirements, with attention paid to anonymization, privacy, and cybersecurity threats. Local storage as well as cloud- or edge-based data management systems may be considered.
    - Note that the *ISS itself* must be capable of independent data management supporting the functions related to real-time intersection control system adaptation and warning system control. Further, the ISS must be capable of providing detailed road user path/trajectory data (both observed and predicted) for external asynchronous safety engineering analysis.
- Wireless Communications and Positioning – A roadside unit or other form of infrastructure may be included if the proposed ISS concept utilizes some form of wireless connectivity—perhaps to include 5G connectivity, V2X, Wi-Fi, or other near-field communications. In addition, infrastructure-based positioning may support GPS or its equivalent.
- Intersection control system interaction – The ISS should be capable of real-time interconnection with existing modern intersection control systems (assume, at minimum, compliant with prevailing industry standards and protocols). The ISS may specify a collection of complementary actions related to the classes of road users at a particular intersection where there are differentiable control mechanisms: e.g., traffic signal or dynamic signage for vehicles, separate indicators and dynamic signage for bike lane users, and pedestrian indicators. The roadside infrastructure may be assumed to provide secure interconnection to the intersection traffic signals (via a signal cabinet for example) and to a central traffic management system for that jurisdiction (potentially through a wireless or fiber optic link).
- Warning system – The ISS must feature a vulnerable road user and vehicle warning system (or both vulnerable road user and vehicle warning systems). Such a warning system(s) may require one or more alarm types ranging from audible alarms, visual alerts, and other more advanced real-time alerts, such as a warning to a wirelessly connected vehicle, for example. The warning

system(s) must be capable of alerting vulnerable road users who are visually or hearing impaired and offer ADA-compliant operation. Vulnerable road users cannot be assumed to have wireless connectivity.

- Interoperability and extensibility considerations – An interoperable and extensible ISS solution must not degrade the underlying existing safety of any intersection at which it is deployed. Interoperability considerations include integration with existing systems at intersections as well as coordination among neighboring intersections with a deployed ISS. Further, the ISS should:
  - be upgradeable by virtue of a modular hardware and software design;
  - use open architectures to the fullest extent possible, including features such as open-source software and Application Programming Interfaces (API) libraries to encourage integration with varied control systems;
  - utilize industry-accepted software development practices;
  - be intrinsically cybersecure; and
  - maintain data privacy protections.
- Event reporting for performance measurement and system improvement – Interaction between the ISS and the intersection control system must support recording both crash and near-miss events, including tagging those events to support further safety and operations analysis at the central traffic management system. This includes supporting retrospective analyses of false-positive and false-negative warnings, unintended consequences, and site-specific tailoring or optimization.

High-Level ISS Requirements. An ISS should have the following high-level capabilities:

- Anticipate potential unsafe conditions and identify appropriate and timely traffic control system plans that can prevent or mitigate these conditions.
- Provide warnings to vehicles and vulnerable road users reliably, minimizing false positive and false negative warnings. Warnings must be provided in a way that all vulnerable road users and drivers may be alerted, whether they are wirelessly connected or not.
- Maintain consistent and reliable system operation and performance under a range of potential operational conditions (including variable weather, visibility, and pedestrian and vehicle demand patterns).
- Provide a cost-effective safety solution (See Section IV, *ISS Incremental Costs* for additional context) that results in a demonstrated reduction in intersection crashes and vulnerable road user fatalities across a variety of roadway intersections.
- Have a feasible path to rapid commercialization and deployment within 10 years, including the ability to be calibrated or customized for individual intersection locations. At scale considerations include streamlined maintenance and operations requirements to ensure equitable and sustainable safety impacts over time.
- Allow upgradeability and modularity as well as interoperability and data transfer capability with existing signal operating systems and traffic management systems.
- Monitor performance of the system by defining, storing, and analyzing false positives, false negatives, crash and near-crash rates, and other unintended consequences.

V. Prizes

Participants will compete for an overall Challenge prize competition (Stage 1) purse of up to $6,000,000. Prizes will be structured as follows:

- Stage 1A: Concept Assessment
  - Up to 10 prizes may be awarded in Stage 1A, with a maximum of one prize awarded per participant or team.
  - Each Stage 1A prize will have a maximum of $100,000.
  - The total value of all Stage 1A prizes will be a maximum of $1,000,000.
- Stage 1B: System Assessment and Virtual Testing
  - Multiple prizes may be awarded in Stage 1B, with a maximum of one prize awarded per participant or team.
  - Each Stage 1B prize will have a maximum of $1,000,000.
  - The total value of all Stage 1B prizes will be a maximum of $5,000,000.

VI. Rules

Note: U.S. DOT reserves the right, in its sole discretion, to (a) cancel, suspend, or modify the Challenge, and (b) not award any prizes if no entries are deemed worthy.

Eligibility

The Challenge is open to individuals and teams (participants) from the academic, research, and business communities including, but not limited to, universities and other institutions of higher learning, research institutions, technology companies, and entrepreneurs. If any potential prize winner is found to be ineligible for any reason, including for failure to comply with Challenge rules, an alternate winner may be selected.

To be eligible to win a prize under this Challenge, an individual or entity (participant):

1. Shall register to participate in the Challenge under the rules as outlined in this document.
2. Shall comply with all the requirements under this announcement and any subsequently announced rules for the prize competition.
3. In the case of a private entity, shall be incorporated in and maintain a primary place of business in the United States or U.S. territory,
4. In the case of an individual, whether participating singly or as a part of a team, shall be a citizen or permanent resident of the United States or U.S. territory.
5. Shall not be a DOT employee; and
6. Shall not be another Federal entity or Federal employee acting within the scope of their employment (all non-DOT Federal employees must consult with their agency Ethics Official to determine whether Federal ethics rules limit or prohibit the acceptance of a cash prize stemming from a Federally sponsored prize competition).

In addition, these two restrictions apply to recipients of other Federal funds:

1. Federal grantees or recipients of Federal cooperative agreements may not use Federal funds to develop submissions for this Challenge unless consistent with the purpose of their grant award or cooperative agreement; and
2. Federal contractors may not use Federal funds from a contract to develop prize competition applications or to fund efforts in support of a prize competition submission.

Note: DOT reserves the right to disqualify any submission that it deems, in its discretion, to violate these Official Rules, Terms & Conditions.

Liability and Insurance Requirements

By registering and entering a submission, each participant agrees to assume any and all risks and waive claims against the Federal Government and its related entities, except in the case of willful misconduct, for any injury, death, damage, or loss of property, revenue, or profits, whether direct, indirect, or consequential, arising from their participation in this competition, whether the injury, death, damage, or loss arises through negligence or otherwise. By registering and entering a submission, each participant further represents and warrants that it possesses sufficient liability insurance or financial resources, *to the extent permitted by applicable law*, to cover claims by a third party for death, bodily injury, or property damage or loss resulting from any activity it carries out in connection with its participation in this competition, or claims by the Federal Government for damage or loss to government property resulting from such an activity. Competition winners shall be prepared to demonstrate proof of insurance or financial responsibility in the event DOT deems it necessary.

Payment of the Prize

Cash prizes awarded under this Challenge will be paid to the individual or Team Lead directly by DOT through electronic funds transfer. Winner(s) will be responsible for any applicable local, State, and Federal taxes and reporting that may be required under applicable tax laws. The DOT will comply with the Internal Revenue Service withholding and reporting requirements, where applicable.

Confidential and Business Information

Challenge submissions and communication with DOT are subject to the Freedom of Information Act (FOIA, 5 USC 552). If the application includes information that the applicant considers to be a trade secret or confidential commercial or financial information, the applicant should do the following: (1) Note on the front cover that the submission “Contains Confidential Business Information (CBI)”; (2) mark each affected page “CBI”; and (3) highlight or otherwise denote the CBI portions. DOT protects such information from disclosure to the extent allowed under applicable law. In the event DOT receives a FOIA request for the information, DOT will follow the procedures described in its FOIA regulations at 49 CFR 7.29. Only information that is ultimately determined to be confidential under that procedure will be exempt from disclosure under FOIA. DOT may proactively publish any application information that is not marked as CBI.

Representation, Warranties, and Indemnification

By entering the Challenge, each Applicant represents, warrants, and covenants as follows:

- Applicant is the sole author, creator, and owner of their Submission;

- The Submission is not the subject of any actual or threatened litigation or claim;
- The Submission does not and will not violate or infringe upon the intellectual property rights, privacy rights, publicity rights, or other legal rights of any third party;
- The Submission does not and will not contain any harmful computer code (sometimes referred to as “malware,” “viruses,” or “worms”); and
- The Submission, and contestants use of the Submission, does not and will not violate any applicable laws or regulations.

If an Applicant is unable to make any of the warranties as stated above, Applicant must provide a clear written explanation of the reason(s) it cannot make any specific warranty. DOT will, in its sole discretion, determine whether such explanations are sufficient.

Intellectual Property of Submissions

Applicants can utilize intellectual property developed prior to this prize competition as a part of their Submission. Neither the DOT nor anyone acting on its behalf will obtain any rights in intellectual property developed prior to or during Stage 1A or Stage 1B of this prize competition without the prior written consent of the Participant. By participating in the prize competition, the Participant is not granting rights in any patents, pending patent applications, or copyrights related to the technology described in their submission. However, by submitting their entry, the Participant is granting the DOT and any parties acting on its behalf certain limited rights as set forth herein.

By virtue of their submission to this prize competition, Participants grant to DOT and any parties acting on their behalf the right to:

1. Review, screen, and evaluate submitted materials in per the Judging Criteria as detailed below.
2. Describe the Submission in any materials created in connection with this prize competition.

Participant further grants the DOT, and anyone acting on its behalf the right to publicize Participant’s name and, as applicable, the name of Participant’s team members and/or the name of any Entity that assisted in preparing Participant’s submission. Such authority includes posting or linking to the Participant’s submission on DOT websites, including the Challenge website, and inclusion of the Participant’s submission in any other media, worldwide. More specifically, such authority includes the right to copy, distribute, publicly display, and publicly perform all parts of Participant’s submission that would not otherwise be exempt from disclosure under FOIA.

VII. Judging

Stage 1A Judging Criteria

Four judging criteria will be used in Stage 1A. All criteria have approximately the same weight. Only submissions that meet the eligible criteria (see Section VI, *Eligibility*) will be evaluated.

Technical Merit

- The proposed Intersection Safety System (ISS) Concept demonstrates a technically feasible and compelling path to prototype testing and development that:

  - satisfactorily addresses all *Minimum ISS Capabilities* (see Section IV)
  - meets or exceeds all *High-Level ISS Requirements* (see Section IV)
- The proposed concept provides a technically feasible and compelling solution for suitably robust detection, localization, and classification of both vehicles and vulnerable road users in real-time (see Section II*, Vulnerable Road Users*). The proposed classification is sufficiently refined to differentiate sub-categories of vulnerable road users and vehicles relevant to intersection control.
- The proposed ISS concept has a technically feasible and compelling approach to both monitor and anticipate individual vehicle and vulnerable road user path, pace, and progress while in and near the intersection in real-time.
- The ISS Concept Paper identifies the most relevant technical risks associated with the proposed approach and provides viable mechanisms for the avoidance, elimination, or mitigation of these risks with further development.

Deployment Suitability

- The proposed concept (or its component elements) can be readied to initiate physical system prototyping at the time Stage 2 is scheduled to begin -- and potential replication and deployment at scale within ten years.
- The ISS Concept Paper clearly identifies the specific intersection conditions under which the proposed ISS could be cost-effectively deployed. This includes the clear identification of the specific types of intersection geometry/configuration, intersection control system and features, built environment and land-use, vulnerable road user and vehicular demand levels, and any/all assumptions made regarding where the proposed ISS concept could be cost-effectively deployed.
  - Note that a single, comprehensive ISS solution, while desirable, is not required. ISS concepts tailored to specific high-risk intersection types are encouraged if these specific intersection types are suitably prevalent across the nation.
- The ISS Concept Paper provides a sufficiently detailed assessment of projected ISS costs of at-scale deployment (see Section IV). The supporting narrative provides evidence that ISS costs per intersection can be reduced to a level compelling enough to encourage broad nationwide deployment at high-risk intersections.
- The ISS Concept Paper provides a compelling approach to interoperable deployment at scale, including the utilization of existing communication protocols, relevant standards, and a solution for communication and integration among adjacent intersections.

Alignment with Challenge Vision

- The proposed ISS concept is aligned with the vision of the Challenge, namely to:
  - transform intersection safety through the development of one or more innovative intersection safety systems that identify, predict, and mitigate unsafe conditions involving vehicles and vulnerable road users in real-time.

Participant Team Organization and Qualifications

- Team composition and leadership are clearly presented, including a single overall team leader/point-of-contact (including e-mail and phone information). All team members (individuals and organizations) are clearly identified. DOT will communicate with individual participants and participant teams through the single team leader designated.

- Team experience and qualifications with relevant technologies and systems are sufficient to advance the concept through virtual testing successfully. Specifically, team expertise and qualifications are sufficient to:
    - identify, describe, and mitigate ISS technical risk (see *Technical Merit* criterion above), and
    - accurately assess the timeline for prototyping and deployment of the candidate ISS (see *Deployment Suitability* criterion above).

Stage 1B Judging Criteria

Stage 1B judging criteria are expected to be similar to Stage 1A judging criteria. Complete Stage 1B judging criteria will be provided when Stage 1B is initiated.

VIII. How to Enter – Stage 1A

TIP: The system times out after 20 minutes of inactivity, so be sure to click "Save Draft' often to save your work. The submission package consists of a single Concept Paper uploaded to https://www.challenge.gov/?challenge=us-dot-intersection-safety-challenge:

Concept Paper: All submitted materials must be contained in a single PDF file consisting of a maximum of 15 pages and no larger than 8MB in total file size. *Note that the page and file size limit is absolute*.

- Note: The 15-page limit *INCLUDES* any/all materials submitted, including images and diagrams. A cover page, if included, will count against the 15-page limit. Submissions over the 15-page limit will not be accepted and will be ineligible for prizes.
- Note: Submitted materials in excess of 8MB in total file size will not be accepted and will be ineligible for prizes.

There is no required format for this submission, but respondents should carefully consider how their submission addresses the Stage 1A judging criteria (above) and provides all of the information necessary for the evaluation of the concept and the capability of the respondents.

Text in the Concept Paper may be no smaller than 11-point font size with 1" margins. Text in tables or graphics of any font size are acceptable provided they are legible.

Please contact safeintersections@dot.gov if you experience any technical difficulties while submitting your proposal. Emails received after 5:00 PM ET may not receive a response until regular business hours resume.

Enhancing Intersection Safety through Federated Learning on Dynamic Multimodal Data Sets

1 Problem Statement:

The Nashville Metro Area faces challenges in ensuring optimal safety at critical intersections. Current systems lack real-time adaptability, scalability, and data-centric prediction capabilities, increasing vehicle and road user vulnerability. There's an imminent need for an intersection safety software system for four pivotal intersections that employs Federated Machine Learning. This technology can analyze and predict traffic patterns without central data storage, ensuring efficient response while maintaining user privacy. The system must include sensing and perception features to predict vehicle and road user behaviors. Given budget constraints, the cost must not exceed USD 10,000 per intersection.

Furthermore, it should be capable of seamless wireless communications, accurate positioning, and effective interaction with existing intersection control systems. An integrated warning system should alert users of potential hazards. The software must be interoperable, allowing for future integration with emerging technologies and extensible, facilitating scalability. Lastly, an event reporting feature is crucial for continuous performance evaluation, enabling systemic improvements. This solution substantially mitigates intersection-related incidents, protecting the community's well-being while optimizing traffic flow.

2 Summary:

Intersection-related collisions represent a significant and pressing challenge to the safety of our road users, with consequences ranging from minor inconveniences to devastating fatalities. Improving the safety of pedestrians, bicyclists, and other vulnerable road users is of critical importance to achieving the objectives of the U.S. Department of Transportation (DOT) National Roadway Safety Strategy (NRSS) and DOT's vision of zero fatalities and severe injuries across our transportation system. According to data from the National Highway Traffic Safety Administration (NHTSA), 10,626 traffic fatalities occurred at roadway intersections in the United States in 2020, including 1,674 pedestrian and 355 bicyclist fatalities. These fatalities at crossings represent 27% of the 38,824 road traffic deaths recorded in 2020. Preliminary estimates for 2021 point to further increases, with pedestrian fatalities up 13% and pedal-cyclist fatalities up 5% compared to 2020

As cities expand and evolve, the demands on our transportation network also grow, bringing into sharp focus the critical need for innovative, scalable, and efficient safety systems at intersections. Nashville Department of Transportation (NDOT), in collaboration with Tennessee State University (TSU), is motivated by a sincere commitment to improve the lives of our community members, ensuring their safety as they navigate the intricate web of Nashville's roads.

We recognize the enormous potential of cutting-edge technologies to redefine the paradigms of road safety. Our request for this funding stems from an understanding of effectively tackling the prevailing challenges at intersections. We must combine advanced technological solutions with our existing expertise. Resources are pivotal in driving this transformation, and this fund represents a beacon of hope for our community.

With the funds granted, our primary objective is to delve deep into research to conceive, develop, and refine a cost-effective and efficient intersection safety system. Grounded in the principles of federated learning, we envisage a cloud-edge platform for each intersection seamlessly connected to centralized servers. This system will monitor, anticipate, and mitigate unsafe intersection conditions and empower our infrastructure to 'learn' and 'adapt' in real-time.

Our collaborative focus is on enhancing the safety measures at Railroad Highway Grade crossings – a nexus of rail and road where the room for error is minimal. By integrating advanced sensing

mechanisms and predictive analytics, we are working to significantly reduce risks at these crossings, ensuring a smooth and safe passage for both rail and road users.

Securing this funding will be transformative for our current research trajectory. While our endeavors in Railroad Highway Grade crossing safety are gaining momentum, this financial injection would enable us to extend our research boundaries to encompass road intersection safety. Leveraging our insights from railroad intersections, we are poised to unearth novel strategies and technologies that can be applied to road intersections, catalyzing the realization of a holistic, integrated, and adaptive safety system.

Looking ahead, our collaborative ambition stretches beyond the confines of Nashville. Rooted in the bedrock of innovation and community welfare, our overarching research goal is to architect safety systems that are effective and scalable. We envisage a future where our innovations serve as a gold standard, paving the way for nationwide, and potentially even global, adoption. As intersections transform with the ebb and flow of urbanization, our solutions will stand as robust sentinels, ensuring future generations' safety.

In conclusion, our plea for this fund is more than merely soliciting financial assistance. It is an invitation for the U.S. Department of Transportation to partner with us in crafting a future where every intersection, regardless of its complexity or location, is a haven of safety. With the confluence of resources, expertise, and vision, we can chart a course to a safer, more intelligent, and more connected transportation ecosystem for all.

3 Background Research:

Integrating Artificial Intelligence (A.I.) and Machine Learning (ML) technologies in highway junction safety has emerged as a promising frontier for academic research and practical implementation. These advanced technologies offer a plethora of solutions aimed at enhancing the safety, efficiency, and adaptability of roadways to dynamic traffic conditions [1][2][3][4][5][6]. While the potential benefits are significant, applying deep learning techniques in this context presents challenges, most notably the requirement for large datasets and substantial computational resources. These requirements not only escalate the operational costs but also raise concerns regarding data privacy and security [7][8][9]. Previous studies have suggested using a hybrid cloud-edge architecture to address the computational inefficiencies. This architecture balances the data processing load between localized servers, often called the "edge," and a centralized cloud system. However, this approach, while effective in some respects, still incurs a high computational cost and latency, making it less than ideal for real-time applications [10][11][12]. Considering these challenges, the focus of the current research is threefold. First, we aim to significantly reduce the computational time required for model training and inference by eliminating the necessity for data transfer between localized servers and centralized cloud systems. Second, we are committed to enhancing the accuracy of models in real-time implementations, thereby making the system more reliable for immediate decision-making processes. Lastly, we introduce an innovative framework based on intelligent federated learning at the edge-cloud interface. This framework is meticulously designed to tackle the unique challenges of ensuring safety at highway intersections.

4 SYSTEMS MODEL:

4.1 Intersection safety system (ISS) architecture:

The Intersection Safety System (ISS) needs to predict and prevent potential collisions at intersections by understanding the real-time movements of vehicles and vulnerable road users, especially when they lack wireless connectivity. Implementing federated learning-based A.I. and ML solutions will enable the ISS to analyze local data from various sources efficiently, ensuring timely and adequate warnings for all road users, regardless of their connectivity status. We propose an intelligence AI-driven edge-cloud-based automated system design for providing ISS. Figure 1 depicts the proposed framework.

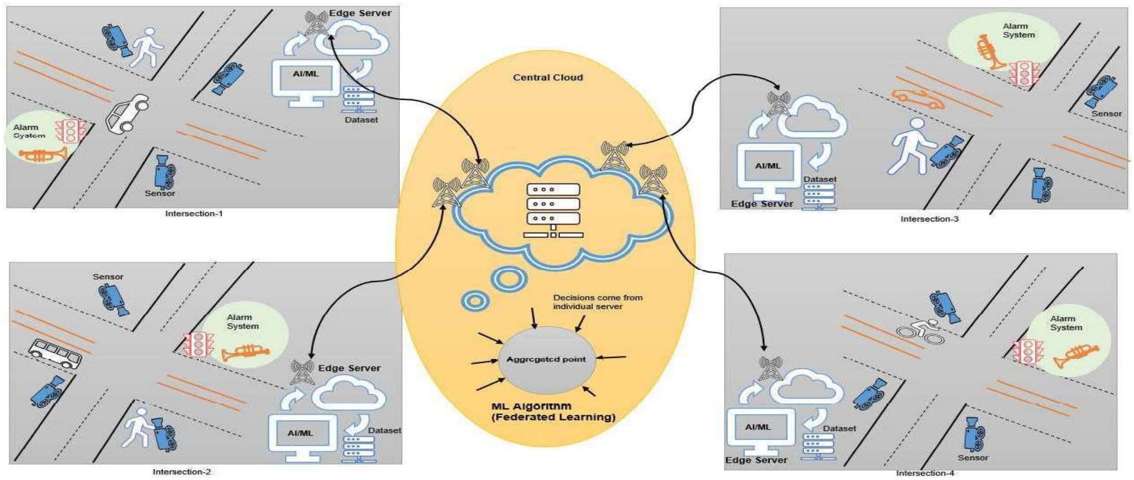


Figure. 1: Proposed AI-driven framework for ISS

4.2 Proposed AI-driven federated learning-based edge-cloud solutions for ISS:

In ML, where data processing demands are high, efficient system design can save costs, especially in cloud-based environments where computational and storage costs can escalate with inefficient structures. Figure 1 represents multiple intersections connected with the principal central server. Each intersection edge server will be incorporated to store the real-time data captured by several sensors (camera, radar, lidar, and infrared) and for real-time decisions made by AI-based federated learning. Federated learning is an ML approach that trains the model across multiple devices or edge servers while keeping the data localized. Instead of sending all the data to a central server for training, federated learning sends the model to the data, allowing each device or server to train the model on its local data. Then, only the model updates (not the data itself) are sent back to a central server, where they are aggregated to improve the global model. This approach prioritizes data privacy and efficiency.

4.3 Federated Learning: A Mathematical Overview for Object Detection and Classification:

Federated Learning (F.L.) is a machine learning approach in which a model is trained across multiple devices or servers while localizing the data. The primary goal is to train shared models without centralizing the data, thus addressing privacy and data security concerns.

Local Training: Each client k trains the model on its local data D_k for E epochs, producing an updated model with parameters θ_k. The local update can be represented as:

$$\theta_k^{t+1} = \theta^t - \eta \nabla L(D_k, \theta^t)$$

Where: $\theta^t$is the model parameter at iteration t, η is the learning rate, L is the loss function, which can be a combination of classification loss and localization loss for object detection task.

Model Aggregation: Clients send their updated model parameters θ_k to the central server. The server aggregates these updates to produce a new global model. A simple aggregation method is the weighted average:

$$\theta^{t+1} = \sum_{k} w_k \, \theta_k^{t+1}$$

Where W_k is the weight for client k, often operational to the size of the local dataset D_k.

4.4 Implementation of Federated Learning in ISS:
Modern urban intersections are poised to benefit from the integration of edge servers, forming a cohesive network connected to a centralized cloud infrastructure. In the proposed framework:

- A.I. algorithms are strategically deployed at each intersection on the respective edge servers, which house the local data pertinent to that intersection.
- These algorithms are tailored to learn autonomously, adapting to their specific intersections' unique traffic patterns and conditions. This results in diverse data-driven models that capture the nuances of different intersections.
- Periodically, post-processing, each intersection's model refines its feature extraction techniques by leveraging datasets from other intersections, enhancing its predictive capabilities.
- Subsequently, these refined algorithms transmit only their enhanced feature extraction methodologies to a central aggregation point within the cloud server, ensuring data privacy.
- After assimilating insights from all intersections, the central server broadcasts a comprehensive and robust model back to each intersection. This model is equipped to make informed decisions, particularly concerning the safety of vulnerable road users.

Central to this framework is the principle of federated learning. It ensures that while devices continuously learn and adapt from local data, the raw data remains confined to its original location, and only the distilled knowledge (akin to refined feature extraction techniques) is centrally shared and aggregated.

4.5 Optimizing Intersection Safety: A Cost-Effective and Time-Efficient Federated Learning Approach in Edge-Cloud Infrastructure:

Integrating federated learning within edge-cloud infrastructure offers a novel approach to optimize intersection safety, addressing real-time responsiveness and data privacy concerns. By decentralizing the training process across edge servers at individual intersections, computational demands on a central server are significantly reduced, leading to cost savings. The localized data processing at the source, through edge servers, ensures timely decision-making, which is crucial for preventing potential collisions and ensuring road user safety. The overarching architecture minimizes data transfer costs and accelerates the model training process, as data doesn't need to be sent back and forth between central and local servers. This innovative approach combines the strengths of both edge computing and federated learning, paving the way for a more efficient and cost-effective solution to enhance intersection safety.

4.6 The action of alarm system in intersection safety:

When the A.I. model finds a potential danger in the intersection, they raise their stop sign to halt traffic. In the same way, the ISS can change traffic lights or send out warnings to prevent accidents. If the vulnerable road user doesn't notice the guard's stop sign, the guard might shout or whistle to get their attention. Similarly, ISS has ways to alert vehicles and people, even if they don't have special devices to receive warnings. The ISS acts like a super-smart crossing guard on duty, ensuring everyone crosses the intersection safely. Figure 1 also shows the alarm system at each intersection.

5 PRELIMINARY WORK:

5.1 Recent research Progress for Railroad Highway Grade crossing safety (RHGC):

Our latest study gathered specialized video footage (Figure 2) from various grade-level crossings featuring pedestrians, automobiles, buses, lorries, and bikes. This data was then processed using a unique edge-cloud-based WBS ensemble model optimized for machine learning. The algorithms were trained and validated on high-performance computing systems within the engineering laboratory at Tennessee State University. We propose an infrastructure incorporating an edge-cloud architecture, with object recognition and segmentation models situated on the edge server at the grade crossing. This server is linked to monitoring cameras, enabling immediate, on-site data analysis. This configuration reduces latency and optimizes network bandwidth by transmitting only crucial, processed data to the centralized cloud. The system architecture seamlessly integrates cloud and edge computing capabilities. Advanced A.I. and machine learning technologies underpin the object detection and segmentation algorithms, enhancing the system's overall responsiveness. To augment our research further, we are exploring federated learning approaches to reduce computational time and improve algorithmic accuracy, thereby eliminating the need for data transfer from local to central servers.

Train Detection at level crossing	Stages involved in an automated level crossing.

Figure 2: Sample AI and ML Application for automated level-crossing to detect the oncoming train.

5.2 RHGC model architecture:

In our study on RHGC object detection, we developed a novel strategy known as weighted-based fusion (WBF) to address the limitations of the non-maximum suppression (NMS) method. We submitted a high-quality publication for review at the annual Transportation Research Board (TRB) meeting in 2024. With the NMS method, bounding boxes presume to pertain to a solitary object when their intersection over union (IoU) exceeds a certain pre-established threshold. Thus, the box filtering process depends on selecting this single IoU threshold value, which affects the model's performance. Setting this threshold is complex; one might lose if objects are close together. NMS removes extra boxes and struggles to create averaged predictions from different models. The critical difference between NMS and WBF is that WBF uses all the boxes, not just some. NMS removes extra boxes, but WBF makes a new box (a fused box) using all the prediction boxes. Our proposed WBF ensemble model combines YOLOv8m, YOLOv8l, and YOLOv8x. YOLOv8 models outperform previous YOLO versions, including YOLOv5 and YOLOv7.

Moreover, compared with YOLO models trained on 640 image resolution, all the YOLOv8 models exhibit improved throughput while maintaining a similar parameter count. In our research for RHGC object detection, the efficacy and advancements demonstrated by the YOLOv8 models have proven highly promising and influential. The primary objective of ensemble models is to minimize the generalization error of predictions. Figure 3 represents the WBS-based ensemble model.

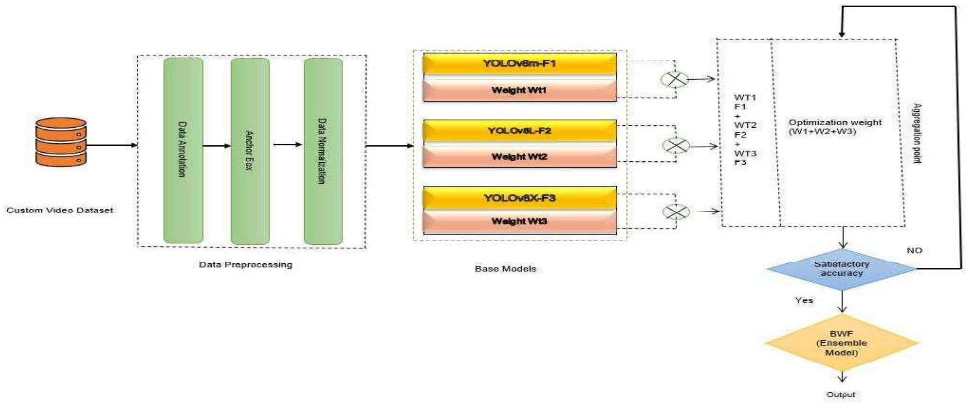


Figure. 3 represents the WBS-based ensemble model architecture.

5.3 Preliminary Model Result Analysis:

Our research evaluates the WBF ensemble model's RHGC safety performance utilizing several traditional ML criteria, including confusion matrix, precision-recall curve, training and validation loss, and accuracy. Figure 4 demonstrates the model's true positive, true negative, false positive, and false negative rates in the confusion matrix. The model has excellent actual favorable rates of 95% % and 100% for the car and people classes, respectively, with a car class false positive rate of 0.05%. The overall model accuracy is 97%. Figure 5 depicts the precision-recall curve, a crucial parameter for evaluating models in class imbalance situations. It shows the precision-recall trade-off. Figure 6 shows the training and validation loss and accuracy curves, measuring model performance, identifying overfitting and underfitting, optimizing hyperparameters, monitoring training progress, and comparing models. Losses decreasing with time suggest the model optimally. Extensive testing in RHGC safety applications substantiates the validity and reliability of our proposed models.

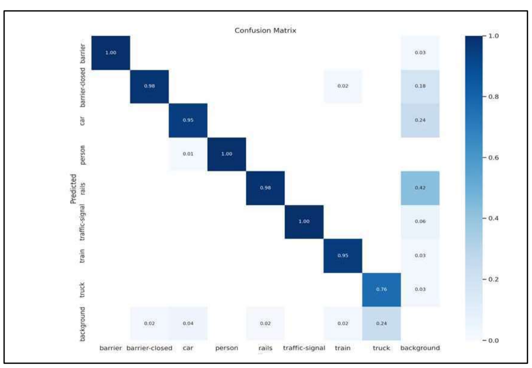


Figure 4: Confusion Matrix

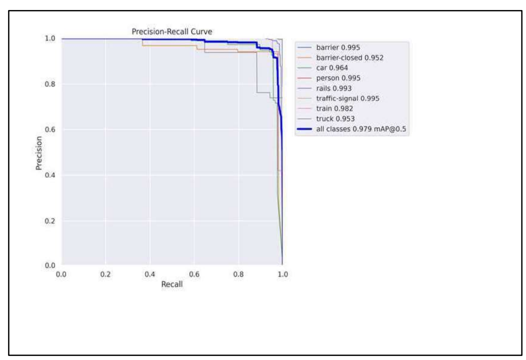


Figure 5: ROC Curve

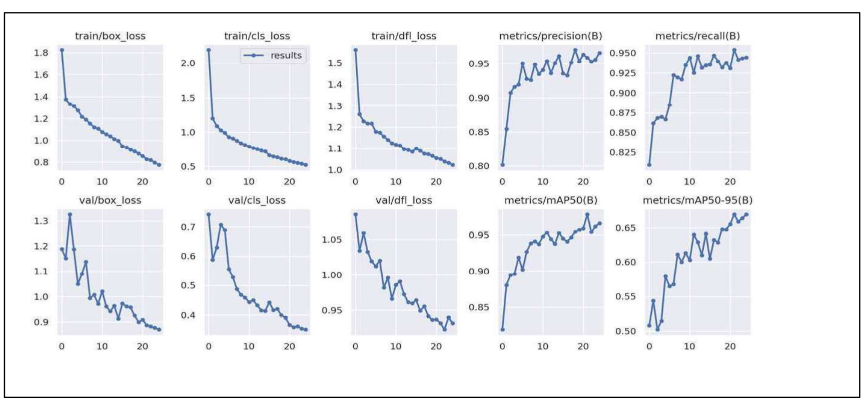


Figure 6: Training and Validation loss and accuracy

6 PROJECT MANAGEMENT PLAN

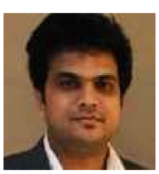
6.1 Project Schedule

Task	Description	Q1	Q2	Q3	Q4
Project Initiation	- Define project objectives and goals.				
	- Identify stakeholders and create a stakeholder communication plan.				
	- Form a project team.				
Research and Analysis	- Conduct research on the intersection safety problem.				
	- Analyze existing data and solutions.				
	- Identify key challenges and opportunities.				
Requirements Gathering	- Define specific requirements for the solution or proposal.				
	- Engage with subject matter experts to gather insights.				
Equipment Procurement and Installation					
Developing software systems for intersection safety	- Create a design or concept for the proposed solution.				
	- Develop technical specifications.				
	- Consider user experience and interface design.				
Prototyping and Development	- Build a prototype or develop the proposed solution.				
	- Test and iterate on the solution as necessary.				
Implementing the software systems in four intersection					
Validation of the system and correction and implement.	- Conduct thorough testing				
Final report and lesson learning delivery					

7 Participant Team Organization and Qualifications

The long-term success of this project will occur in conjunction with the input from NDOT and TSU.

TSU will do the applied research on federated learning-based intersection safety. NDOT will provide the implementation support selection of four intersections for this pilot implementation around the Nashville metro area. The cross-institute project management team comprises Murad Al Qurishee from NDOT as a project investigator (PI), his team, and Kamrul Hasan, Ph.D. from TSU, as a PI and his team.



Dr. Kamrul Hasan is an Assistant Professor of Electrical and Computer Engineering at TSU. His research interest includes AI and ML-enabled autonomous model development, Physics Informed Deep Learning (PIDL) model development and verification for Transportation Engineering, AI/ ML-enabled cyber risk detection, and mitigation tools development. Since 2020, he has worked as P.I./Co-PI for four research projects funded by the National Science Foundation (NSF), the Electric Power Research Institute (EPRI), and FRA. He authored over 20 peer-reviewed high-impact papers, one book chapter, and one U.S. patent.

Murad Al Qurishee is a highly qualified NDOT's engineer with a Master's in Civil Engineering from the University of Tennessee and a Bachelor's from Chittagong University. His experience includes key roles in traffic management and intelligent transportation systems, managing various projects, overseeing ITS deployment, and ensuring regulatory compliance. Murad is a licensed Professional Engineer and holds several certifications. He has authored multiple research papers and made conference presentations, showcasing his expertise in deep learning and UAV technology for infrastructure assessment. He managed both Federal Grants and State Grants such as CMAQ, ATCMTD, SMART, I-24 ICM corridor, etc. Overall, Murad's diverse skills and accomplishments make him a valuable asset for this project.

8 Budget

Task	**Budget Allocation**
Project Initiation	USD 10,000
Research, Analysis, and Prototype development	USD 55000
Graduate Student's Stipend and Tuition for One year	USD 35,000
Total Budget Allocation	USD 100,000

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APPLICATION FOR U.S DOT Intersection Safety Challenge

METROPOLITAN GOVERNMENT OF NASHVILLE AND DAVIDSON COUNTY

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Diana W. Alarcon
CCA6046554B9461...

9/19/2023

Diana W. Alarcon, Director
Department of Transportation and
Multimodal Infrastructure

Date

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Status: Original 1/22/2024 3:34:00 PM	Holder: Juanita Paulson Juanita.Paulsen@nashville.gov	Location: DocuSign
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Signer Events	Signature	Timestamp
Greg McClarin Greg.McClarin@nashville.gov Security Level: Email, Account Authentication (None)	GAM Signature Adoption: Pre-selected Style Using IP Address: 170.190.198.185	Sent: 1/22/2024 3:39:04 PM Viewed: 1/22/2024 3:41:42 PM Signed: 1/22/2024 3:42:10 PM
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Aaron Pratt Aaron.Pratt@nashville.gov Security Level: Email, Account Authentication (None)	Aaron Pratt Signature Adoption: Pre-selected Style Using IP Address: 170.190.198.185	Sent: 1/22/2024 3:42:14 PM Viewed: 1/22/2024 3:46:50 PM Signed: 1/22/2024 3:46:56 PM
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Kevin Crumbo/mjw MaryJo.Wiggins@nashville.gov Security Level: Email, Account Authentication (None)	Kevin Crumbo/mjw Signature Adoption: Pre-selected Style Using IP Address: 170.190.198.100	Sent: 1/22/2024 3:47:01 PM Viewed: 1/22/2024 3:55:13 PM Signed: 1/22/2024 3:56:27 PM
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Courtney Mohan Courtney.Mohan@nashville.gov Security Level: Email, Account Authentication (None)	Courtney Mohan Signature Adoption: Pre-selected Style Using IP Address: 170.190.198.185	Sent: 1/22/2024 3:56:31 PM Viewed: 1/23/2024 9:29:01 AM Signed: 1/23/2024 9:35:43 AM
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Sally Palmer sally.palmer@nashville.gov Security Level: Email, Account Authentication (None) **Electronic Record and Signature Disclosure:** Accepted: 1/23/2024 8:21:38 AM ID: c36086dc-a9bf-4668-a792-9cf00152de64	COPIED	Sent: 1/23/2024 9:35:47 AM Viewed: 1/23/2024 9:38:31 AM

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