Project Title	Multifront Approach for Improving Navigation of Autonomous and Connected Trucks	
PI (Up to 2)	PI: Imad L. Al-Qadi	Co-PI: Yanfeng Ouyang
Telephone #	(217) 265-0427	
E-mail:	alqadi@illinois.edu	
Institution:	University of Illinois at Urbana-Champaign	
Department:	Civil and Environmental Engineering	
Industry or Government Principal, organization, and contact information	Illinois Department of Transportation	
Government Principal, agency, and contact information	LaDonna R. Rowden. P.E. Bureau Chief of Research Illinois Department of Transportation Bureau of Research 126 East Ash Street Springfield, IL 62704-4766 Phone: (217) 782-2631 Fax: (217) 782-2572 E-mail: LaDonna.Rowden@illinois.gov	
Most relevant CCAT research thrusts (choose all applicable)	__X__ Enabling Technology _____ Planning and Policy _____ Human Factors __X__ Infrastructure Design and Management __X__ Control and Operations __X__ Models and Implementation	
Funding Request	$232,060	
Matching Funds and Source (if any)	$232,060	
Total Project Cost	$464,020	
Contract Number	69A3551747105	
Project start/end dates	January 1, 2019 – December 31, 2021	

Project Abstract	Connected and autonomous vehicles (CAV) and autonomous and connected trucks (ACT) reduce congestion, increase efficiency, and improve safety, but they also increase pavement damage. This project will optimize the benefits and drawbacks of ACT at two levels. At the network level, ACT's shipment routing and scheduling strategy for freight transportation that minimizes total cost will be developed. At the corridor level, real-time optimization will be performed; hence, ACT and platoons can adjust their configuration as they roll and external conditions change (e.g., wind speed, pavement condition). Accurate pavement damage prediction and ACT positioning affect successful deployment of the optimization in both levels. Accuracy of pavement damage prediction will be increased by including resting period, so the effect of truck separation in a platoon can be quantified. ACT positioning control will be enhanced by modifying material characteristics to allow better communications with the pavement.
High-level implementation plan	The research team will outline a methodology for network shipment routing and incorporate the findings in the mechanistic-empirical pavement design guide (MEPDG).
Project Metrics	Metrics to be used to assess project performance are grouped in two categories: project management and research outcomes. For the project management, a quarterly progress report will state the work performed as a percentage of the proposed work plan. The research outcomes will be quantified by the number of peer-reviewed journal papers published, presentations at national and international conferences, and technical reports.
Web Links: [leave blank until project approval]	ccat.umtri.umich.edu

PROPOSAL DESCRIPTION

1. INTRODUCTION

The benefits of connected and autonomous vehicles (CAV) on improving traffic condition have been revealed from field tests even with low market penetration. Large scale implementation of CAV will lead to a better controlled traffic flow, which reduces congestion and maintenance of infrastructures, while increasing safety and efficiency. Although research in CAV technology historically has been driven by small-sized vehicles, there has been significant development in autonomous and connected trucks (ACT) to lower the freight costs. Given that almost 70% of freight transportation carried by heavy duty trucks (class 8 or higher), the potential economic benefits is significant. Introduction of ACT is expected to result in drastic changes in operational characteristics of freight shipments. Intelligent technologies used in ACT enable connection among vehicles, which allow the formation of truck platoons. A truck platoon is a convoy of trucks traveling in a very close distance. Research of truck platooning using semi-autonomous trucks resulted in a reduction in congestion and braking/accelerating; and improved safety, traffic flow, and fuel efficiency. However, the channelized traffic of truck platoons results in increased pavement damage. A balance between ACT's benefits and shortcomings can be achieved by addressing the problem at the network and corridor level.

At the network level, freight transportation covers large distance trips through series of highway corridors, or medium distance trips over local road network. Consequently, navigation of truck platoon in a series of highway corridors can be optimized for freight transportation to minimize the total cost incurred from freight operation, traffic congestion, and infrastructure management. At the corridor level, platooning configuration can be also optimized. Optimal platooning configuration in a corridor depends on the wind speed, local pavement condition, local traffic condition, and maximum allowable speed. These conditions change as ACT travels the corridor. Real-time optimization enables the decision makers to account for these variations alongside the platoon trip to optimize reduction in fuel consumption and pavement damage. The challenge with real-time platoon configuration optimization is that the aerodynamic simulation is too computationally expensive to be conducted in a real-time fashion.

Since pavement damage affects the optimization at the network and corrido levels, its accurate quantification is imperative. The lateral position of platoons is significantly different than that for regular traveling trucks. In addition, ACT would reduce the level of randomness of trucks' lateral position significantly. This results in channelized traffic, which reduces pavement service life and increases maintenance and rehabilitation costs. Furthermore, the distance between trucks in a platoon is minimized, which results in a shorter resting period between two load applications. The reduction of resting period may hinder healing of asphalt concrete (AC) in flexible pavements and increase erosion potential in rigid pavement. This leads to accelerated damage accumulation within pavement structures. Channelized loading was considered in previous UTC funding cycle; however, the effect of reduced distance between each successive truck load application was not captured because of the lack of mechanistic models.

Pavement-to-vehicle communication is essential not only for safe deployment of autonomous vehicle (AV) but also for the implementation of a predefined configuration. Currently,

pavements are not designed to assist ACT navigation. In order to cover safe navigation in all weather conditions, direct communications to the roadway is necessary. Therefore, pavements must either incorporate embedded sensors (e.g., RFID) that control/navigate the AV during inclement weather or the paving material must be a passive sensor with the AV actively reading.

2. OBJECTIVE

The main objective of this study is to improve the mobility of ACT while causing the least pavement damage. The following four sub-objectives are defined:

- Develop an optimization framework at the network level to determine the shipment routing and scheduling strategy for freight transportation that minimizes the total cost incurred from freight operation, traffic congestion, and infrastructure management.
- Create a real-time optimal platooning control strategy to optimize truck lateral shifts within a lane to reduce damage to the pavement, and corresponding maintenance and rehabilitation costs.
- Improve the accuracy of pavement damage prediction by including in-between trucks resting period.
- Investigate the feasibility of implementing passive sensing paving materials for controlling lateral positioning of ACT.

3. TECHNICAL APPROACH

The technical approach is divided into four blocks. Block I and Block II deal with the optimization at the network and corridor levels, respectively. Block III focuses on the effect of a resting period on pavement damage, while Block IV addresses passive sensing paving materials.

3.1. Block I: Road Network Optimization of ACT Platoons

From the network-level perspective, trips made by ACT platoons can be planned to minimize operational and societal costs. Upon studying the impact of ACT on highway corridors and local roads, the ACT platoons may pre-allocated over a road network on both spatial (routing) and temporal (trip scheduling) dimensions.

Typical freight trips' needs include one-to-one (e.g. material depot to manufacture factory), one-to-many (e.g. depot to consumers), and many-to-many (e.g. multi-commodity transportation). The control variable may include routing of freight shipments, load distribution, ACT platoon configuration, and pavement rehabilitation schedule. The goal is to achieve optimal operational cost and impact on public road users (e.g. congestion and road deterioration). Factors to be considered, including road network topology, freight origin/destination distribution (location and quantity) and background traffic (public traffic), shall be acquired or estimated.

ILLINOIS CENTER FOR TRANSPORTATION

For any given scenario, the inter-dependency among freight demand, traffic equilibrium, and incurred cost is yet to be studied. Previous efforts designed an ACT platoon configuration, where the decision variables included inter-vehicle separation and lateral displacement that minimizes the sum of user (fuel consumption) and agency cost (pavement rehabilitation) under the tradeoff between air drag reduction and pavement deterioration acceleration. This module provides building blocks for each roadway corridor (an edge in a network) that takes input of freight traffic throughput (number of trucks with given weights) and outputs the minimized cost of that corridor. The network level optimization can then be modeled as a bi-level optimization problem. The lower level is the operational strategy (platoon configuration) of a route (series of corridors); and the upper level consists of routing, shipment scheduling, and throughput allocation under traffic equilibrium to achieve minimum operational and societal cost.

A conceptual expression of the total cost function may be:

$$\min_{L_{i,j,t}} Cost = \sum_t \sum_i (Cost_{fuel} + Cost_{pave} + Cost_{congestion}) \tag{1}$$

where the first and second terms are functions of platoon configuration, and the third term is a function of traffic flux. Volume freight trucks will be converted into equivalent passenger vehicles (or vice versa) in the traffic flux. The upper level problem assigns throughput (number of trucks) to be shipped via edge i at time t (Figure 1). The lower level solver takes such input and returns the cost of each edge to sum up as the total cost. This framework may also expand to accommodate multi-mode or multi-commodity transportation.
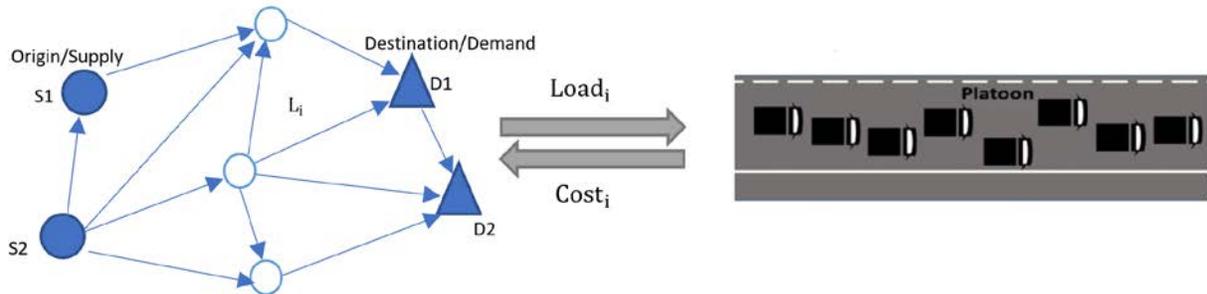
Figure 1. Schematic for road network optimization of platoons

3.2. Block II: Real Time Optimization

To optimize the lateral position of trucks in a platoon, its impact on truck aerodynamics and pavement damage accumulation should be simulated. In the real-time optimization problem, the decision variable is the lateral spacing of trucks, and the objective function is the fuel cost plus the pavement maintenance cost. Therefore, this real-time optimization framework consists of three elements: aerodynamic modeling, pavement analysis, and the real-time optimization itself.

Different tools will be used in each element of the framework: i) Wander 2D model proposed by the Illinois Department of Transportation will be used for pavement analysis; ii) the real-time optimization problem will be solved using a genetic optimization algorithm; and iii) metamodels

constructed based on convolutional neural networks (CNN) will be applied in the aerodynamic modeling.

As for the training data, several two- and three-dimensional numerical simulations will be conducted in a FE tool to compute the aerodynamic drag. The simulation will be performed for various combinations of number and configuration of trucks, truck types and sizes, maximum allowable speeds, wind speeds and directions, and traffic conditions. Given the training data, the CNN metamodel will predict the velocity and pressure field in the platoon.

In the construction of the CNN metamodel, the recently developed physics-informed (PI) regularization method will be used to increase the metamodel's accuracy (Nabian and Meidani 2018). This novel regularization method is suitable for systems subjected to known governing laws in the form of a partial differential equation, which are the Navier-Stokes equations in this case. Prior knowledge about the physics of the problem will be used to push the trained models to satisfy the Navier-Stokes equations. This can be done by creating a regularization term that accounts for the underlying physics by penalizing divergence from the governing equations. The PI regularization method offers two main advantages: i) it prevents overfitting, resulting in significantly smaller generalization errors when compared to other regularization methods; and ii) it produces metamodels that are physically interpretable, as opposed to the ones that are trained using purely data-driven approaches.

The proposed real-time optimization framework will ultimately offer a real-time operation strategy for optimized configuration of a truck platoon, which can result in reduced fuel consumption and pavement damage.

3.3. Block III: Resting Period and Pavement Damage

Although the impact of resting period and healing on asphalt concrete (AC) has been investigated, there is limited work to include them in the state-of-the-practice pavement design guideline. Due to this limitation, a holistic assessment of platooning impact on pavements may not be accurate. This block aims to fill this gap in the literature by developing a surrogate function that inputs resting period and other design parameters to obtain change in AC damage. This surrogate model can be interpreted as a shift factor that considers healing and modifies the damage resulting from current design approaches. The shifted damage considering AC healing D_h can be calculated as follows:

$$D_h = D_0 \times f\,(h, RP, M, T) \tag{2}$$

where, (h, RP, M, T): developed surrogate model or shift factor that is function of pavement layer thicknesses (h), resting period (RP), material properties (M), and temperature (T); D_0 = damage computed without rest period.

The shift factor will be developed by using advanced mechanistic approaches that simulate AC behavior considering resting period such us finite elements. The simulations will be supported by an experimental program to determine parameters of the proposed model.

(a) Resting period without platooning

(b) Resting period with platooning where $S_2 \ll S_1$
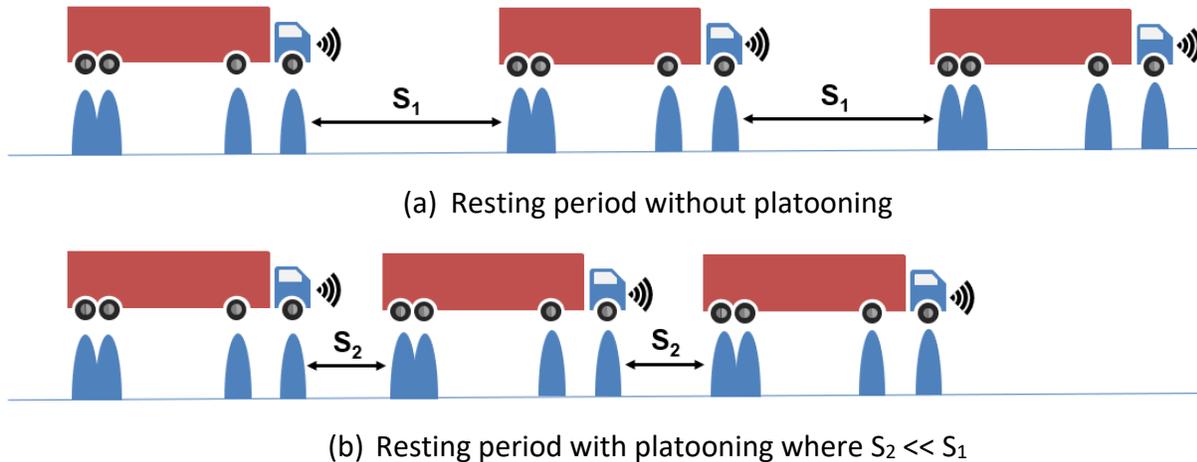
Figure 2. Demonstration of reduction in rest period due to platooning

Once the shift factor is developed, it can be integrated with the current pavement design approach to assess the impact of resting period reduction due to platooning. Finally, an optimization strategy will be investigated by combining pavement design with truck aerodynamic models developed in the previous UTC funding cycle by UIUC researchers to determine optimum intervehicle spacing.

3.4. Block IV: Passive Sensing Paving Material

Aggregates control most of the bulk properties in concrete and AC, so replacing normal aggregates at certain locations (edges of the lanes or center of the lanes) with aggregates or mixtures having higher electromagnetic (EM) properties (e.g., steel slag or steel fiber reinforced concrete) would create a distinct EM signature in the road (See Figure 3). Pavement sections could also be modified to have lower EM reflection, which would attenuate more signals. Distinct higher or lower EM wave reflection would allow ACT to detect the specific lateral location (either edge or center) of the lanes and position the AV correctly during a loss in the primary navigation unit.
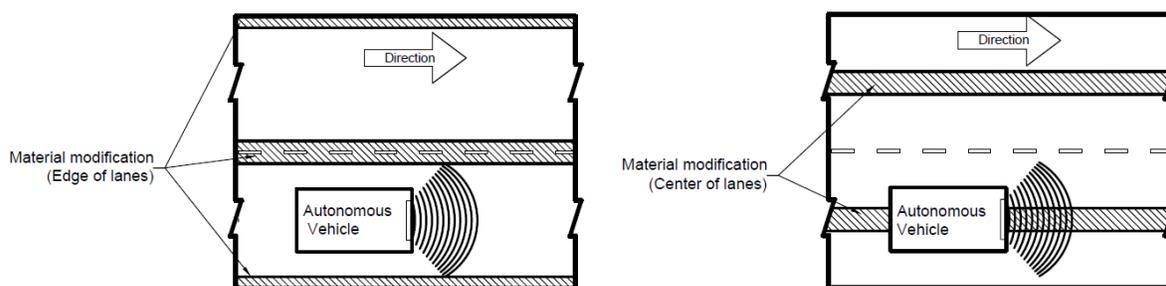
Figure 3. Material modification at the lane edges (left) and lane center (right).

A feasible approach is to cut a slot on the road surface and either insert a partial depth/width material with different EM properties, and use RADAR or eddy currents to properly position the ACT during primary navigation interruption and/or inclement weather. RADAR is more weather insensitive compared to other sensors currently used in AV (Wenger 2007, Wenger and Hahn

2007, Gresham et al. 2004). In addition, RADAR's low cost allows deployment of large number of sensors in AV, making it a feasible option to increase lateral position accuracy during navigation (Charvat 2017).

An eddy current technique can also be explored as an alternative. This method uses the electromagnetic phenomenon to detect EM materials embedded near the pavement surface. Electromagnetic fluxes are created around coils by supplying power, and electromagnetic materials in the pavement disturbs the EM flux created by the coils (Szymanik 2016). The disturbance of electromagnetic flux can be used to determine location of electromagnetic materials within the lane and thus determine the vehicle's position.

4. PROPOSAL TASKS

Besides literature review and preparation of final report, the objectives of each block will be accomplished by performing the following tasks:

4.1. Block I Tasks:

4.1.1. Model Formulation
The formulation of each component of the cost function will be studied in depth. For instance, the congestion quantification as a function of traffic flow will be expanded to address the impact of ACT platoons. The upper level model will be constructed to reflect the planning decisions considered by trip makers. It will also be integrable such that the optimal routing strategy can be found minimizing the total societal cost.

4.1.2. Algorithm Development
An optimization algorithm will be developed to solve the bi-level problem. It shall be able to cope with various scales and scenarios, and to achieve optimality in a timely manner. The optimization framework for network freight transportation using ACT fleets will incorporate specific options (lane use and platooning options) that are enabled by ACT. The framework integrates factors such as background traffic and route parameters (network layout, distance, O-D location, etc.) to optimize the choice of route(s), steady-state platoon sizes, and platooning configuration on each route. The framework also consists of a subroutine model that optimizes the scheduling for pavement rehabilitation activities.

4.1.3. Case Study
The algorithm will be applied to typical cases to show its implementation and capabilities.

4.2. Block II Tasks:

4.2.1. Pavement Analysis
Wander 2D model proposed by the Illinois Department of Transportation will be used in the pavement analysis.

4.2.2. Aerodynamic Modeling

Metamodels constructed based on Convolutional Neural Networks (CNNs) will be used for aerodynamic modeling. Numerical simulations in FE tool of aerodynamic drag for will provide the training data.

4.2.3. Real-Time Optimization
Genetic optimization algorithms will be used to solve the real-time optimization problem, where aerodynamic drag and pavement damage is minimized.

4.3. Block III Tasks:

4.3.1. Mechanistic Analysis of Resting Period on Pavement Damage
Advanced simulation tools will be used to capture the effect of resting period on pavement damage. The simulation matrix will include speed, spacing between trucks, temperature, pavement structure, and loading magnitude to quantify effect of resting period on pavement damage. Three-dimensional FE modelling approach with damage prediction capabilities will be used in this task.

4.3.2. Experimental Characterization
The proposed surrogate model includes parameters that cannot be obtained from simulations only. Those properties such as material characteristics, temperature, magnitude of resting period, and loading patterns will be developed using both simulations and experiments. Fatigue experiments will be conducted using a uniaxially-loaded cylindrical AC specimens.

4.3.3. Surrogate Model Development
The selected mechanistic analysis tool will be run at chosen values from the previous tasks in this block. The shift function will be fitted to resulting data points.

4.3.4. Intervehicle Distance Optimization
The developed shift factor function will be integrated in the optimization framework developed by the researcher team. The outcome of this task will be the determination of optimum intervehicle distance that considers fuel economy and pavement damage throughout its life-cycle.

4.4. Block IV Tasks:

4.4.1. Material Identification for Pavement Modifications
Materials that can modify the electromagnetic properties within portland cement concrete and/or AC pavements will be identified. The properties should be easily detected within conventional paving materials. Normal aggregates could be replaced in certain locations with steel slag aggregates, steel fiber reinforced concrete, or magnetic aggregates to modify the EM properties at pre-determined lateral locations. These inserted paving materials could either attenuate or amplify the signal to create distinct signature that the AV can detect.

4.4.2. Laboratory Testing of Materials and Sensor Detectors
Several experimental test beams with distinct electromagnetic properties using various materials identified in the previous task will be cast in the laboratory. Initially, 12x12x6 concrete beams with a 1-by-2 in notch will be constructed. Material that has distinct EM properties will fill the notch.

A sensor array will be developed to identify the variation in EM properties across the beam and at different longitudinal positions. The following steps will be followed to develop any passive sensor and material combination prior to field testing.

a) Evaluate sensors to detect material variation and sensor location.
   i. Propose the type of passive sensors.
   ii. Suggest appropriate frequency or antenna modifications to detect the variations in EM properties.
   iii. Suggest number and dimension of coils and frequency (different frequency has different penetration depth) required to detect magnetic property using eddy method.
b) Evaluate the effectiveness of materials with various EM and magnetic properties that can be differentiated from the surrounding concrete.
c) Evaluate the location and amount of material that could give a detectable signal.

4.4.3. Evaluate robustness of materials and sensors under simulated weather conditions
The robustness of the passive sensor and material combinations under inclement weather conditions will be tested in the laboratory. The modified concrete beams will be tested under surface moisture and ice. The thickness of the water film and ice layer will also be varied. Based on the sensor testing and behavior of the material under adverse weather conditions, necessary modifications will be made to the beam's EM properties. The modifications will ensure passive detection and reliability of the system. Robustness can further be increased by finding any correction factor for inclement weather conditions with water, snow, and ice.

4.4.4. Construction and test in large scale (Pending extra secured funding)
After successfully completing laboratory test, the appropriate material and sensor combination will be implemented on a large-scale pavement at the Advanced Transportation Research and Engineering Laboratory (ATREL), given that funding for the construction of a pavement lane is secured. The sensing system will be attached to a vehicle and the material will be placed in the pavement to validate its ability to keep the vehicle laterally positioned during either inclement weather or failure of the primary navigation system.

5. KEY INNOVATION AND RELEVANCE TO CCAT RESEARCH THRUSTS

The main innovation and relevance of this project can be summarized as follows:

- Traffic equilibrium with mixed traffic and vehicle routing problems (VRP) have been extensively studied; however, very limited work has been done that involves ACT. The benefits of truck platooning can raise interest in the industry and accelerate the implementation pace. In addition, the condensed heavy-weight flow may cause certain popular routes to incur higher rehabilitation and manage costs, if not appropriately controlled. These issues can be addressed by the optimization at the network level.
- Given the significant impact of freight trucks on infrastructure deterioration, and traffic flow motion and equilibrium, the study of ACT at the network level is necessary for

understanding the potential benefit of ACT upon mass implementation.The optimality can also be utilized by traffic engineers or urban planners to predict the impact of platooned ACT fleets on freeway traffic flow and level of service. Such information can further be used by policy makers to develop regulations and/or engineering guidelines on rehabilitation of infrastructure, construction of new routes, or pricing for heavy vehicle permits.

- The adoption of ACT is correlated to condition of transportation infrastructure. In fact, aging and deteriorating infrastructure are considered as one of the main barriers for advancing CAV technologies (Johnson 2017). Given the 20% of roadway miles in poor or mediocre conditions and 9.1% of bridges being structurally deficient or functionally obsolete (ASCE 2017), accurate prediction of pavement damage has become even more important to ensure functional and maintained infrastructure network for ACT advancement.

- Realistically predicting the behavior of any infrastructure rely on accurate representation of the traffic inputs. As one may expect, currently, the traffic inputs for transportation analysis and design tools are characterized by human drivers nature. However, the introduction of ACTs is expected to result in drastic changes in characterization of such inputs, which may require significant modifications to existing infrastructure design guidelines or development of new ones. In this project, two such critical variables for pavement design, resting period and loading pattern will be investigated. The outcome of this project can be used to modify the existing pavement design guidelines that they can accurately assess the changes in characteristics of resting period and loading pattern.

- Allowing communication between AV and pavement will increase the accuracy of ACT positioning in the road. This is crucial for the application in real scenarios of the result from any optimization algorithm.

6. PLAN FOR COLABORATION

Collaboration will be planned with a company supplying autonomous vehicles. Their AV will be outfitted with the proposed sensor system for passive material detection. In addition, collaboration with trucking industry will be initiated on the impact of platooning on the network and infrastructure.

7. PROJECT OUTPUTS

Two optimization procedures will result from this project. The first one will focus on shipment routing and scheduling strategy for freight transportation. The optimization will minimize the total cost incurred from freight operation and ACT. The second optimization will determine, in real-time, the platooning configuration that minimizes pavement damage as traveling conditions change (e.g. pavement condition, wind speed, and truck speed).

In addition, an algorithm to considered resting period on the pavement damage calculation will be provided. The algorithm will be presented in a Matlab or Python script, so it can be readily available for future usage. Finally, pavement material types and test methods (EM or magnetic

properties) for assisting in autonomous vehicles lateral positioning under inclement weather will be specified.

8. TECHNOLOGY TRANSFER AND OUTREACH PLAN

Outreach and technology transfer will target researchers, government officials, students (K-12, undergraduate, and graduate), practitioners, and industry. The following summarizes the technology transfer and outreach activities in which the research team will engage and the main target audience:

- *Kent Seminar:* Kent Seminar is a 1-hour technical presentation held in the ATREL and streamed through YouTube on a weekly basis during the academic semester. The seminar features prominent figures in transportation research and will be used to disseminate research results inside and outside of UIUC's community
- *ICT Newsletter:* The ICT's Newsletter is a quarterly publication prepared by ICT's outreach unit and delivered to more than 6000 individuals. The newsletter will be used to share the impact of this research in lay terms, introduce researcher in this project to the transportation community, and show the presence in national and international conferences
- *TRB Webinar:* Organization such as the Transportation Research Board will also be approached to deliver webinars. The research team has successfully done that with ICT-Wide tool, Sealants, etc.
- *Participation in Conferences:* Presentations at the national and state levels, mainly in regions active with CAV and ACT technologies, will be given as progress is made in the project. In addition, the results of the project will be publicized through road agencies and state DOTs.
- *Bituminous Conference and Transportation & Highway Engineering (THE) Conference:* UIUC transportation faculty organize these two conferences every year, targeting practitioners, technicians, and state DOTs employees. Specifically, THE is a 1.5-days conference attended by 1200 transportation professionals, while the Bituminous Conference is attended by 330 participants.
- *Illinois Engineering Open House (EOH):* EOH is 2-day event in the college of engineering at UIUC attended by students from 600 high schools. This even will be used to introduce connected and autonomous vehicles and the outcomes from this project to high school students.

9. AGREEMENT WITH THE CCAT DATA MANAGEMENT PLAN

The data management plan (DMP) has been reviewed and the project will be complying. Key research products, including processed datasets and technical reports on methodologies, will be subject to an internal quality assurance procedure in which identified graduate students or PIs review the work for inaccuracies.

The Illinois Center for Transportation and the Department of Civil and Environmental Engineering at UIUC have ample storage resources for the proposed project. The project will utilize a shared network to store files so that each person working on the project has access to the most up-to-date files. Within the network, GIS files will have their own folder as do any other specialized datasets (e.g., inputs/outputs for the models). The various storage resources will be backed up regularly. For file access, only one person is allowed to make changes to a file at a time.

10. IRB AND SUBJECT MANAGEMENT

Not applicable

11. ITEMIZED BUDGET AND BUDGET JUSTIFICATION

11.1. Itemized Budget

The itemized budget is presented in Figure 4.

11.2. CCAT UTC Budget Justification

11.2.1. Salaries & Wages
Personnel include UIUC Principal Investigator and other investigators salaries for Imad Al-Qadi, Jeff Roesler, Yanfeng Ouyang, Hadi Meidani, and Hasan Ozer. Salaries also include Communications Coordinator salary, Research Assistant salaries, and Student Hourly salary.
11.2.2. Fringe Benefit Rates
Fringe benefits are budgeted at the current Institutional rates: 41.98% for faculty and staff, 8.02% for RAs, and 7.75% for Hourly.
11.2.3. Domestic Travel
Domestic travel includes travel to trips associated with conducting research projects, and attending meeting. Travel includes airfare, hotel, and per diem.
11.2.4. Materials & Supplies
Includes materials and supplies for research projects.
11.2.5. ATREL Fee
Includes fee for use of the ATREL facilities.
11.2.6. Tuition
Includes 64% of Research Assistant salary.
11.2.7. Indirect Cost Rates
Facilities and Administration (F&A) costs are calculated at 58.6% modified total direct costs (MTDC) per the federally-negotiated rate agreement. MTDC comprises of salaries and wages, fringe benefits, materials and supplies, professional services, travel, and subawards up to $25,000. Student tuition is excluded from MTDC.

Category	University Name: University of Illinois Urbana-Champaign		
Federal Share Funds Available:	$232,060		
Match Funds Needed:	$232,060		
Match Source:	☐ State ☒ Local	☐ Other, Including:	

Please complete your institutions budget by filling in the highlighted cells below. The chart below is required from each institution included in the UTC proposal response.

Category	Budgeted Amount from Federal Share	Budgeted Amount from Matching Funds	Total
Center Director Salary			$ -
Faculty Salary	$ 27,015	$ 20,247	$ 47,262
Administrative Staff Salaries			$ -
Other Staff Salaries	$ 4,750	$ -	$ 4,750
Student Salaries	$ 61,737	$ 79,240	$ 140,977
Staff Benefits	$ 18,285	$ 14,855	$ 33,140
Total Salaries and Benefits	$ 111,787	$ 114,342	$ 226,129
Student Tuition	$ 39,192	$ 50,714	$ 89,905
Permanent Equipment [1]			$ -
Expendable Property, Supplies, and Services [2]	$ 7,820		$ 7,820
Domestic Travel	$ 2,000		$ 2,000
Foreign Travel [3]	$ -		$ -
Other Direct Costs (specific) [4]			$ -
Total Direct Costs	$ 160,799	$ 165,056	$ 325,854
F&A (Indirect) Costs	$ 71,262	$ 67,004	$ 138,266
Total Costs	$ 232,060	$ 232,060	$ 464,120

Figure 4. Itemized budget

11.3. UIUC Cost Share Budget Justification

11.3.1. Salaries & Wages
Personnel include salary other UIUC investigators: Jeff Roesler, Yanfeng Ouyang, and Hadi Meidani. Cost share salaries also include Research Assistant salary.

11.3.2. Fringe Benefit Rates
Fringe benefits are budgeted at the current Institutional rates: 41.98% for faculty and staff, and 8.02% for RAs.

11.3.3. Tuition
Includes 64% of Research Assistant salary.

11.3.4. Indirect Cost Rates
Facilities and Administration (F&A) costs are calculated at 58.6% modified total direct costs (MTDC) per the federally-negotiated rate agreement. MTDC comprises of salaries and wages, fringe

12. SHORT BIOS OF THE PIs

12.1. Imad L. Al-Qadi

Al-Qadi is the Bliss Professor of Engineering, the founding director of the Illinois Center for Transportation (ICT) at the University of Illinois at Urbana-Champaign (UIUC). He is the founder of the UIUC-UIC-NU Smart Transportation Infrastructure Initiative (STII). A registered professional engineer, Al-Qadi is an elected ASCE Distinguished Member, emeritus member of TRB Committee AHD25, and an honorary professor at several universities in Europe, China, and the Middle East. He is the editor-in-chief of the *International Journal of Pavement Engineering* and served as an associate editor or regional editor for other publications. He has received many national and international awards, including NSF Young Investigator Award, IGS Award, ASCE James Laurie Prize, ARTBA Steinberg Award, ASCE Turner Award, D. Grant Mickle Award, Limoges Medal of Merit, and many others. Al-Qadi is past president of the board of governors of the ASCE Transportation and Development Institute and founder and current chair of the executive board of the Academy of Pavement Science and Engineering (APSE). He also served as group leader of the ISAP Technical Committee on Interlayer Systems and a member of the USDOT Truck Size and Weight Study National Committee and the TRB Operation and Maintenance Group. He is the past chair of TRB Preservation and Maintenance Section; TRB Subcommittee AFD70-2 (founder); TRB Committee AHD25; TRB Subcommittee AFS70-2 (founder); ASCE Highway Pavement Committee; and ASCE Design, Construction, and Maintenance Executive Council. His leadership record also includes chairing more than 20 international conferences and being an active member of many professional organizations. Al-Qadi's scholarly record features more than 650 authored/coauthored publications. His research has resulted in development of new tests, testing specifications, advanced modeling and simulation of pavement loading, pavement-layer interface and crack development, and analysis of radar electromagnetic wave interactions with roads and bridges.

12.2. Jeffery Roesler

Jeffery Roesler holds B.S., M.S., and Ph.D. degrees in Civil Engineering from the University of Illinois at Urbana-Champaign. He has been on the faculty of CEE at Illinois since August 2000. Prior to joining the faculty at the University of Illinois, Dr. Roesler was a Visiting Post-Doctoral Researcher at the University of California at Berkeley. He has taught undergraduate and graduate courses in pavement and materials engineering, geometric design of roadways, project-based learning in CEE, and CEE professional practice.

Dr. Roesler is an active participant in the Transportation Research Board (TRB) and is a member of the TRB Rigid Pavement Design Committee (AFD50) and Full-Scale/Accelerated Pavement Testing Committee (AFD40). He is currently President of the International Society of Concrete Pavements (2016-2018). He is a registered Professional Engineer in the state of California.

12.3. Yanfeng Ouyang

Dr. Ouyang earned hi Ph.D. in Civil Engineering from University of California at Berkeley, 2005. He holds a B.Eng. in Civil Engineering (summa cum laude from Tsinghua University, Beijing, China, 2000), a M.S. in Industrial Engineering and Operation Research (University of California at Berkeley, 2005) and a M.S. in Civil Engineering (University of Washington, 2001).

Dr. Ouyang's research mainly focuses on developing strategic, tactical, and operational models and solution methods for problems that arise in the multidisciplinary and interdisciplinary areas of transportation systems, operations management, network optimization, and logistics systems planning. His research portfolio covers a combination of theoretical research on complex engineering systems and real-world applications that address high-priority societal needs (e.g., renewable energy systems, food supply chains, and sensor networks).

12.4. Hadi Meidani

Dr. Meidani earned his Ph.D. in Civil Engineering from the University of Southern California (2012). He holds a B.S. in Civil Engineering (K.N. Toosi University of Technology, Iran 2002), a M.S. in Structural Engineering (Sharif University of Technology, Iran 2005) and a M.S. in Electrical Engineering (University of Southern California 2012).

After Ph.D. graduation, he has been a Postdoctoral Scholar in the Department of Aerospace and Mechanical Engineering at USC (2012-2013) and a Postdoctoral Research Associate in the Scientific Computing and Imaging Institute at the University of Utah (2013-2014).

12.5. Hasan Ozer

Hasan Ozer is currently working as a Research Assistant Professor in the Civil Engineering Department of University of Illinois at Urbana-Champaign. Hasan Ozer holds a B.S. degree in Civil Engineering (Middle East Technical University, 1999), M.S. in civil engineering (Northwestern University, 2005), and Ph.D. in Civil Engineering (University of Illinois at Urbana-Champaign, 2011). His master thesis was about developing and implementing wireless sensor networks for crack displacement measurements. In his research at the University of Illinois, he specializes in computational mechanics, infrastructure sustainability, fracture mechanics, pavement interfaces, experimental characterization of asphalt mixture materials and sealants.

13. REFERENCES

American Society of Civil Engineers. (2017). The 2017 report card for America's infrastructure. American Society of Civil Engineers (ASCE).

Charvat, G.L. (2017). Small and short-range radar systems. CRC Press.

Gresham, I., Jenkins, A., Egri, R., Eswarappa, C., Kinayman, N., Jain, N., Anderson, R., Kolak, F., Wohlert, R., Bawell, S.P. and Bennett, J. (2004). Ultra-wideband radar sensors for short-range vehicular applications. IEEE Transactions on Microwave Theory and Techniques, 52(9), pp.2105-2122.

Johnson, C. (2017). Readiness of the road network for connected and autonomous vehicles. RAC Foundation: London, UK.

Nabian, M. A., & Meidani, H. (2018). Physics-Informed Regularization of Deep Neural Networks. arXiv preprint arXiv:1810.05547.

Szymanik, B., Frankowski, P. K., Chady, T., & John Chelliah, C. R. A. (2016). Detection and inspection of steel bars in reinforced concrete structures using active infrared thermography with microwave excitation and eddy current sensors. Sensors, 16(2), 234.

Wenger, J. (2007, October). Short range radar-being on the market. In Radar Conference. EuRAD 2007. European (pp. 255-258). IEEE.

Wenger, J. and Hahn, S. (2007, September). Long range and ultra-wideband short range automotive radar. In Ultra-Wideband, 2007. ICUWB 2007. IEEE International Conference on (pp. 518-522). IEEE.

14. LETTER OF COMMITMENT FROM THE INDUSTRY OR GOVERNMENT PRINCIPAL

Illinois Department of Transportation

Office of Planning & Programming / Bureau of Research
126 East Ash Street / Springfield, Illinois 62704

December 14, 2018

Henry Liu
Research Professor
University of Michigan
Transportation Research Institute
2901 Baxter Road
Ann Arbor, MI 48109-2150

Dear Professor Liu:

On behalf of the Illinois Department of Transportation (IDOT), I am pleased to submit this letter of support for the proposal by the University of Illinois at Urbana-Champaign on Multifront Approach for Improving the Navigation of Autonomous and Connected Trucks to the UTC Center of Automated and Connected Transportation.

The proposed idea will be beneficial to the State of Illinois and is within the "Autonomous Illinois" vision announced by Governor Bruce Rauner on October 25, 2018. As an economic and transportation hub, Illinois is interested in the impact of platooning on shipment routing and freight transportation, as well as the effect of the concentrated, high frequency loading on our roadway system. This research will assist with efforts to be a leader in the field of connected and autonomous vehicles.

Recognizing the importance of this vital research effort, IDOT is pleased to support this innovative idea and encourages you to select this project for funding.

Sincerely,

LaDonna R. Rowden, P.E.
Bureau Chief of Research