<table>
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<th>Project Title</th>
<th>Intelligent Sidewalk De-icing and Pre-treatment with Connected Campus Maintenance Vehicles</th>
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<tbody>
<tr>
<td>PI (Up to 2)</td>
<td>Darcy Bullock</td>
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<tr>
<td>Telephone #</td>
<td>(765) 494-2226</td>
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<tr>
<td>E-mail:</td>
<td><a href="mailto:darcy@purdue.edu">darcy@purdue.edu</a></td>
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<tr>
<td>Institution:</td>
<td>Purdue University</td>
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<tr>
<td>Department:</td>
<td>Darcy Bullock</td>
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</tbody>
</table>
| Industry Principal, company, and contact information | Brian McGavic  
McGavic Outdoor Power  
2280 Westfield Road Noblesville IN 46060 |
| Government Principal, agency, and contact information | Dr. Samy Noureldin  
Director, Joint Research Transportation Program  
Indiana Department of Transportation  
1205 Montgomery Street, P.O. Box 2279  
West Lafayette, Indiana 47906  
(765)463-1521 ext. 250  
snoureldin@indot.in.gov |
| Most relevant CCAT research thrusts (choose all applicable) |  
_X_ Enabling Technology  
____ Planning and Policy  
____ Human Factors  
____ Infrastructure Design and Management  
_X_ Control and Operations  
_X_ Models and Implementation |
| CCAT Research Theme |                                                                                 |
| Funding Request | $75,000                                                                           |
| Matching Funds and Source (if any) | $75,000  
JTRP Project: SPR_4322 Development of an Intelligent Snowplow Truck that Integrates Telematics Technology, Roadway Sensors, and Connected Vehicles |
<p>| Total Project Cost | $150,000                                                                      |
| Contract Number | 69A3551747105                                                                      |
| Project start/end dates | January 2, 2020 – December 31, 2020                                              |
| Project Abstract | Develop an automated system for precision application of de-icing chemicals on campus and urban sidewalks that will reduce excessive chemical application and will result in less environmental impact, reduced infrastructure aging, and cost savings. The development platform will be a small electric vehicle to provide students the opportunity to have a hands-on development environment that can be safely used on campus without extensive coordination necessary for large commercial vehicles. |</p>
<table>
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<tr>
<th>High-level implementation plan (of Research Outcomes)</th>
<th>The knowledge developed during this research will scale to highways and airports. It will also develop relationships with key industrial partners to develop capabilities in the connected/autonomous space for small campus vehicles.</th>
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SECTION 2  PROJECT ABSTRACT

Develop an automated system for precision application of de-icing chemicals on campus and urban sidewalks that will reduce excessive chemical application and will result in less environmental impact, reduced infrastructure aging, and cost savings. The development platform will be a small electric vehicle to provide students the opportunity to have a hands-on development environment that can be safely used on campus without extensive coordination necessary for large commercial vehicles.

The knowledge developed during this research will scale to highways and airports. It will also develop relationships with key industrial partners to develop capabilities in the connected/autonomous space for small campus vehicles.
SECTION 3 PROPOSAL DESCRIPTION

3a Introduction

The state of Indiana spends about $60M for snow and ice removal in peak years. Local agencies within Indiana spend over $100M annually and nationally over $1B is spent on snow and ice control. Within the state of Indiana even very small precipitation events with cold temperatures can dramatically reduce roadway speeds (Figure 1). During a major event, there are significant disruptions of regional vehicle and freight mobility (Figure 2). These winter weather events also significantly increase crash rates (Figure 3) and it is not uncommon to see up to 300-600 miles of interstate impacted (Figure 4) during a major storm despite significant resources devoted to plowing and deicing activities (Figure 5, 6). The cost and environmental impact of these deicing chemicals applied on roads (Figure 7), airports (Figure 8), and sidewalks (Figure 9) is a national concern with a multi-billion-dollar economic impact.

Recently, the liquid application of deicing chemicals has been migrating to campus (Figure 10). However, to date very little intelligence has been systematically integrated into either highway, airport, or sidewalk de-icing systems. It is widely believed that improved automation and calibration of systems applying de-icing chemicals could substantially reduce the environmental impact with economic savings exceeding $100M annually.

Problem Statement & Research Objective

One of the challenges in developing improved systems is developing an effective laboratory environment for students to safely conduct experiments. On road testing (Figure 7) or on airport (Figure 8) is not feasible during extreme winter weather events. This project proposes developing an automated sidewalk deicing system that integrates commercial equipment, precision agriculture sprayer control models, and real-time data to construct a sidewalk based precision de-icing system (Figure 10). The objective would be to adapt precision agriculture sprayer application (Figure 11a) to respond to real-time weather forecasts to apply de-icing chemicals to sidewalk routes on campus. A campus friendly electric vehicle (Figure 11a) would likely be used as the deployment platform. These application rates would vary considerably, ranging from 0 on top of tunnels (that already melt snow from heat and should not be sprayed to avoid corrosion), to medium width sidewalks (standard application rates) to very wide sidewalks (heavy application rates to avoid dilution) and reduced application rate in environmentally sensitive areas (Figure 12).

The proposal next describes the Research Team’s technical approach which itemizes the proposed tasks, timelines and deliverables. Then the key innovations of the expected research product and its relevance to CCAT are described. This is followed by the plan for collaboration; planned project outputs, outcomes, and impacts; implementation plan; and the technology transfer and outreach plan. Finally, this proposal affirms its compliance with data management plan and any IRB requirement if needed, and cites relevant references to support the discussions in the research background and technical approach, and key innovations.
Development of an automated system for precision application of de-icing chemicals on campus sidewalks that will reduce excessive chemical application and result in less environmental impact, reduced infrastructure aging, and cost savings. The development platform will be either a small ATV or electric vehicle to provide students the opportunity to have a hands-on development environment that can be safely used on campus without extensive coordination necessary for large commercial vehicles. The team will integrate real-time weather forecasts from the national weather service (Figure 1) along with high fidelity GPS and precision agriculture technology.

The Indiana Department of Transportation (INDOT), Purdue Airport, and Indianapolis colleagues will be integrated into the project team as advisors. We will also integrate private sector partners from the small campus utility sector into the team to ensure solutions developed during this research work on campus sidewalks as well as scale to large roadways and airside infrastructure.

In Section 3c, we list and describe the 11 tasks of our technical approach.

The research mechanisms that will be used to accomplish the research will include literature reviews, questionnaire surveys and interviews (of campus facility managers, city infrastructure managers), and analysis of data. With regard to the Literature Review, the research team will obtain, analyze, describe and critique available information on automation of deicing operations and connectivity benefits. This will include agency reports, academic research, industry reports and information in the media.
3c. Proposed Tasks, Timelines and Deliverables

3c.1 Proposed Tasks

1. Procure vehicle and de-icing tanks.
2. Develop and integrate precision agriculture systems to provide real-time rate control (and application rate measurement) of de-icing chemicals (Figure 11).
3. Develop GIS map of campus sidewalks to develop geo-fences that can be used for defining application rates and critical areas where deicing chemicals should not be applied (Figure 12).
4. Develop models for application rates that should be used for various forecast weather conditions (Figure 1).
5. Coordinate with campus safety officials and physical plant to develop protocol for testing/deploying. Conduct experiments with just water (not brine) to test rate control (Figure 12). This will be done both visually and with high resolution GPS maps.
6. Coordinate with Purdue physical plant to partner with them on 2019/2020 winter operation activities on select sidewalk routes.
7. Deploy equipment during 2019/2020 storms. Surface salinity, surface temperature and visual condition will be recorded throughout the storm by undergraduate student participants.
8. Develop after review for each storm with quantitative and qualitative assessment of surface conditions.
9. Throughout season, monitor application rate of material campus wide, as well as on selected automated routes and prepare post season summary and recommended best practices for 2020/21 winter season.
10. Develop recommendations on how lessons learned on sidewalk experiments can be adapted to airports and highways. Present that information at a winter operations conference. In addition to standard technical reports, we envision a series of hands on workshops. These can either be done during snow events, or summer months. We envision this being an excellent opportunity to engage with pre-college students in hand-on driving experience to learn about emerging connected and autonomous opportunities.
11. Prepare technical report. The final report will be submitted on December 31, 2020.

3c.2 Timelines

The start date of the 12-month study is Jan 1, 2020 and the end date is Dec 31, 2020 (Fig 3). The draft final and final reports will be submitted Oct 31, 2020 and Dec 31, 2020, respectively.

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3c.3 Deliverables
A final report will be submitted December 31, 2020.

3d Key Innovation and Relevance to CCAT
The Midwest USDOT Center for Connected and Automated Transportation (CCAT) has categorized its research focus into six areas: enabling technologies, policy and planning, human factors, infrastructure design and management, modeling and implementation, and control and operations. This proposal addresses the following thematic areas enabling technologies, operations, and implementation. Application of connected and autonomous concepts to campus winter operations maintenance activities. These concepts will scale well to roadways and airside airport operations (Figure 7, Figure 8)

At the current time, wintertime deicing operations are carried out with relatively little or no connectivity or automation. Preliminary field tests at Purdue, Fishers, and other locations have been very successful, and have generated tremendous interest among stakeholders, and it has been agreed generally that deicing operations can be significantly enhanced if the deicing vehicles are made to have connectivity or automation capabilities.

Connectivity in this context, that is, V2V, V2I and V2X, could refer to the exchange of information between the following entities:

- a deicing vehicle and other deicing vehicles;
- a deicing vehicle and a central command such as the sub-district headquarters;
- a deicing vehicle and the infrastructure being served (for example, roadway, sidewalks, and tunnels regarding their locations, dimensions, depths);
- a deicing vehicle and weather stations;
- a deicing vehicle and regular on-road vehicles (to avoid collisions), pedestrians (to avoid conflicts), and owners of vehicles parked in snow lanes.

Automation, in the context of deicing operations, refers to the use of equipment to partly take over from the human, the task of the deicing operations, and can occur as any combination of:

- Using automation to determine the current or expected future severity of coldness, snow fall, or ice deposition. Machine learning models could be used to analyze meteorological data to make these assessments or predictions.
- Using automation to determine the amount of deicing chemical to be applied. Based on the determination of the current or expected future severity of ice deposition, coldness, or snow, models can be used to assess the optimal amount of material to apply to the pavement.
- Using automated equipment to spread the deicing chemical. For wide pavements such as those at highways and airports, regular trucks are currently used to spray the deicing chemical. For narrow pavements such as sidewalks and small pavement areas, spraying is done mostly manually, and therefore presents an opportunity to deploy smaller automated equipment such as those shown in the photos of this proposal.
- Using automation to operate the deicing vehicle. The spraying of wide or narrow pavements can be carried out using autonomous vehicles instead of human-driven vehicles. Doing this can save costs and permit deicing operations in extreme climates or hazardous environments.

The proposed study will not address all these areas of connectivity and automation as they pertain to deicing operations. Rather, only a few areas will be addressed, and if successful, subsequent studies will be proposed to examine how the other areas of connectivity and automation could be incorporated to further enhance the strategic and operational task of pavement deicing.
3e  Plan for collaboration

The Research Team will strive to bring together the diverse strengths, knowledge, and experiences of the CCAT consortium, its members, affiliates, and industry partners to work toward the shared goal of developing and deploying connected and automated transportation systems. This includes partnerships with public, private, academic, and not-for-profit entities, as well as universities. Such collaboration will span across individual researchers working on different CCAT topics within the research areas, CCAT institutions, and the six CCAT research themes.

3e.1 Relationship with the industry or government principals named in the proposal. 
The Indiana Department of Transportation (INDOT), Purdue Airport, and Indianapolis colleagues will be integrated into the project team as advisors. We will also integrate private sector partners from the small campus utility sector into the team to ensure solutions developed during this research work on campus sidewalks as well as scale to large roadways and airside infrastructure. Mr. Brian McGavic, CEO of McGavic Outdoor Power, at Noblesville, Indiana, has worked extensively with the members of the research team in past studies and field demonstrations. Dr. Samy Noureldin is the Director of the Joint Research Transportation Program between Purdue University and the Indiana Department of Transportation. He has worked with the individuals on the Purdue CCAT team for at least 2 decades, on the administration and conduction of research projects that address the traditional as well as the emerging transportation environment.

3e.2 Advisory committee members that will contribute to the implementation plan
Brian McGavic, Samy Noureldin, Debby Bezzina (CCAT administrator).

3e.3 Proposed collaboration activities with CCAT partner institutions
The nature and mechanisms for such collaboration will include:

- Meetings and seminars
- Joint collection of data and data sharing
- Solicit research results from other CCAT researchers as input for the proposed research
- Providing research results to other CCAT researchers as input for their research
- Joint white papers and Joint conference presentations, and joint publication of journal papers

3e.4 Plan to work with other organizations to attract external funding.
Efforts will be made to solicit the partnership of potentially interested organizations including cities and towns, private sector vendors of deicing equipment and chemicals.
3f Planned project outputs, outcomes, and impacts (high-level descriptions) [2 pages max]

3f.1 Outputs
With regard to the above intended new methodologies and technologies, our output mechanisms will include publications, conference papers, and presentations, featured articles on CCAT website(s) or other internet site(s). The developed research product will also serve as an integral part of a new next-generation transportation course (Smart Mobility) that we started teaching at Purdue University in Fall 2018. Beyond these traditional academic outputs, we have arranged to conduct a two day “Ride and Drive” hands on demonstration in Indianapolis as part of the Work Truck show that attracts 15,000 visitors. Participants in the Ride and Drive are decision makers on purchasing de-icing equipment and hands-on demonstrations are very effective for that group of stakeholders.

3f.2 Outcomes
We expect that the product of the proposed research will help increase the body of knowledge and expand the understanding and awareness of more efficient application of de-icing chemicals. Ultimately, this will reduce the funds agency spend on de-icing chemicals and reduce the amount of salt that enters our environmental sensitive watersheds

3f.3 Impacts
Development an automated system for precision application of de-icing chemicals on campus sidewalks that will reduce excessive chemical application and will result in less environmental impact, reduced infrastructure aging, and cost savings. The development platform will be either a small ATV or electric vehicle to provide students the opportunity to have a hands-on development environment that can be safely used on campus without extensive coordination necessary for large commercial vehicles. The knowledge developed during this research will scale to highways and airports. It will also develop relationships with key industrial partners to develop capabilities in the connected/autonomous space for small campus vehicles.
3g Implementation Plan

3.g.1 Activities needed to successfully implement the expected outcomes of the project
CCAT research projects are intended to yield products that will be applied in practice. In view of this, the research team should devise a plan for effectively translating the results of the proposed research into practice and promoting the application of the study products. The product of the research should be designed in such a manner that the product will be readily applicable to practice with minimal implementation barriers.

Task 10 will include a series of workshops for practitioners and pre-college students (Figure 12, Figure 13). These workshops will be scheduled during good weather and during storms. During good weather, only water will be applied to the sidewalks (Figure 12).

Therefore, we intend to undertake the following activities in order to enhance the likelihood of successful implementation:

- Close cooperation, throughout the study, with stakeholders and the audience associated with the research product. These may include individuals from the city agencies, and the transportation agencies (state, counties, cities, and towns), private parking facility operators, AAA, and other organizations involved in metropolitan parking management and operations.
- Learning from the experiences of others who had succeeded (or faced challenges) in implementing CAV research or other related research.
- A well-designed modular implementation plan using appropriate technology transfer tools and techniques to ensure clear understanding of the use and benefits of the study product.
- Use of communication tools for effective technology transfer to make the stakeholders aware of the possible benefits from the research products.
- Offer training of personnel at the implementing organization, as part of the implementation plan.
- Pilot applications of the study methodology, via microsimulation, and additional field demos, to facilitate implementation.
- Recommend ownership of the research products by a specific individual or office at the implementing agency, to foster continued interest, maintenance, support, and enhancements of the study product.

3g.2 Implementation challenges and potential solutions
The possible threats to the implementation of the study product include:

- Hesitation by the implementing organization to deploy a technology that, in their view, may not have been fully tested.
- Underdeveloped base (substrate) for the implementation at that location/agency, such as inadequate data, inadequate equipment, inadequate personnel, and so on.
- Philosophical differences of personnel at the implementing organization.
- Unwillingness of the implementing organization to spend time and money to adopt a new initiative in a time of fiscal austerity, even though the organization realizes that the tool may produce a long-term gain.
- Inconsistency of study results with actions or directions desired or expected by the personnel at the implementing organization.
Technology Transfer and Outreach Plan

The technology transfer and outreach plan for this proposal will be consistent with the CCAT Technology Transfer Plan. Specifically, this research project will deliver several project outputs that will make contributions to both the state of the art and the state of practice. We will disseminate our findings through the print and electronic media, journal publications, conference presentations, websites (of UM-CCAT, Purdue CCAT, Purdue’s Hub for Connected and Autonomous Transportation (Hub-CAT), and the Purdue Global Policy Research Institute (GPRI)) and other outlets.

Target journals include Elsevier’s Transportation Research Part C, Journal of Transportation Engineering, Computer Aided Civil and Infrastructure Engineering, and other journals in the area of AI, CAV and control in engineering. Target conferences will include Transportation Research Board (TRB) Annual Meetings, the Institute for Operations Research and the Management Sciences (INFORMS) Annual Meeting, the International Conference on Ambient Systems, Networks and Technologies and International Symposium on Transportation & Traffic Theory (ISTTT).

Also, we will share our findings and papers through local print media (Journal and Courier, Indianapolis Star), external print media (Chicago Tribune, the New York Times), newsletters of University of Michigan CCAT, Purdue CCAT, Purdue Hub-CAT, GPRI, and social media platforms associated with AASHTO, FHWA, USDOT, and professional open-platform websites such as LinkedIn, ResearchGate.

Compliance with CCAT Data Management Plan

The CCAT DMP has been reviewed and the project will be in compliance with these requirements. If this proposal is selected for funding, a formal data management plan for the project will be submitted.

IRB and Subject Management

Not applicable.

References


4a Budget justification

**Personnel Compensation** $27,491
In accordance with 2 CFR 200, Uniform Administrative Requirements, Cost Principles, and Audit Requirements for Federal Awards, Purdue University tracks and reports its professional personnel on a percent of effort and not on an hourly basis.

- **Principal Investigator / Faculty / Key Person** $11,023
  Salary is requested for 2 week summer effort. His work includes project supervision, information dissemination through publications and conference presentations as well as supporting education and workforce development. The salary calculation is based on the 9-month (academic year) base salary effective 7/1/2019.

- **Graduate Student** $12,423
  Salary is requested for a quarter-time graduate student during the 12 month project.

- **Fringe Benefits** $4,045
  Fringe benefits are budgeted in accordance with university policy.

**Other Direct** $29,991

- **Travel** $4,359
  Travel expenses are requested for faculty, professional staff and/or graduate students. This amount will cover expenditures to attend relevant local or national conferences and workshops (such as CCAT, CUTC and TRB) to present findings.

- **Grad Fee Remissions** $5,160
  Fee remissions are budgeted per standard university policy

- **Capital Equipment** $20,472

- **Purchase of small electric vehicle (GEM® eL XD) is requested. The automated brine application system for this vehicle (costing $     ) is provided as cost share for the project.**

**Indirect Costs** $17,518
Purdue University’s approved F&A rate of 55% is charged to the modified total direct costs (MTDC) incurred on this project. Grad fee remissions and Equipment are excluded from the MTDC base.
4b. Hiring plan for students and/or faculty

We intend to produce top quality research as part of this work. As such, we will continue to nominate our students for specific local, regional and national awards including departmental and college-level outstanding dissertation prizes, the CUTC best MS and PhD thesis prizes, and the UTC Student of the Year prize. For this reason, we will, as much as possible, seek to hire graduate students that will be eligible candidates for awards in these various categories. We will organize or partake in graduate school research fairs for undergraduate students at Purdue University in order to tap this pool of talent from the senior undergraduate students who will be eligible for these awards.

4c. Itemized budget

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<td>v. Total Other</td>
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viii. Total Direct Cost Amount | $57,482
ix. Indirect Cost Amount     | $17,518
x. Total Amount Requested    | $75,000
Darcy Bullock

Dr. Darcy Bullock is a Professor of Civil Engineering at Purdue University and serves as the director of the Joint Transportation Research Program. Bullock is a Registered Professional Engineer in Indiana and has 25 years of experience in the industry working closely with vendors, state agencies, and USDOT, and colleagues at other universities. Bullock’s teaching, research and consulting interests have been in the general area of traffic engineering. He received a B.S. in Civil Engineering from the University of Vermont, and a M.S. and a Ph.D. in Civil Engineering from Carnegie Mellon University.

Over the past two decades, Bullock has completed several projects with the Federal Highway Administration, Federal Aviation Administration, National Cooperative Highway Research Program, National Science Foundation, Department of Homeland Security, Houston Airport System (Houston Intercontinental Airport), Kenton County Airport Board (Cincinnati Airport) as well several state and local transportation agencies. The results of those projects are published in over 200 journal articles, conference proceedings, and technical reports, several of which have received national awards from ASCE, TRB and ITE.
December 16, 2019

Samuel Labi  
Professor of Civil Engineering  
Purdue University  
550 Stadium Mall Drive  
West Lafayette, IN 47907-2051

Subject: CCAT Proposal for Darcy Bullock

Dear Professor Labi:

I am writing to confirm my support for the proposal entitled “Intelligent Sidewalk De-icing and Pretreatment with Connected Campus Maintenance Vehicles” submitted by Darcy Bullock to the Center for Connected and Automated Transportation (CCAT).

I will collaborate with the research team to develop an automated system for precision application of de-icing chemicals on campus and urban sidewalks. The development platform will be a small electric vehicle that provides students and staff with the opportunity to have a hands-on development environment that can be safely used on campus without extensive coordination necessary for large commercial vehicles. The knowledge developed during this research will develop capabilities in the connected/autonomous space for small campus vehicles and also provide the information needed to scale precision application of de-icing chemicals to highways and airports.

Sincerely,

Brian McGavic  
McGavic Outdoor Power  
2280 Westfield Road Noblesville IN 46060  
317/774-5888  
bmcmgavic@mcgavicoutdoorpower.com
APPENDIX: FIGURES AND PHOTOS

Figure 1: Interstate speed profiles, precipitation, solar flux, and air temperature
Figure 2: Extensive impact on regional passenger and freight mobility.

Figure 3: Example relationship between a small winter weather event and crash rates in Crawfordsville District on Jan 16, 2016.
Figure 4: Significant winter events over a four month period (max miles <45mph)

Figure 5: Granular material application, by district

Figure 6: Liquid application rate, by district
Figure 7: Application of granular salt

Figure 8: Application equipment for de-icing liquide at an airport
Figure 9: Excessive application of Granular salt on sidewalk (Indianapolis)

Figure 10: Excessive application of Granular salt on sidewalk (Indianapolis) with home made liquid application system on Purdue Campus.
a) Fossil fuel vehicle with no automation

b) Candidate electric vehicle that can accommodate additional automation growth

Figure 11: Emerging non precision system with no GPS or rate application system that would be adapted to provide precision application of de-icing chemicals

Figure 12: Example testing that can be done safely by students on campus with visual feedback.

Figure 13: Example opportunities for hand-on experiments.