Semi-Annual Progress Report No. 1 – Urban Mobility & Equity Center

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	Morgan State University (Lead Institution) *Virginia Polytechnic Institute and State University* *University of Maryland*
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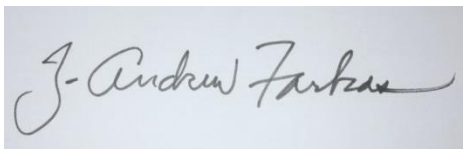
Signature:	

1. ACCOMPLISHMENTS.

What was done? What was learned?

With 16 projects underway and five completed, the Urban Mobility & Equity Center's research goes beyond simply contributing to a body of knowledge and is actively developing metrics, methods, best practices and innovative uses of technology to improve equity and mobility while reducing costs. The results remind us that costs are not just dollars, but also an individual's travel time and the ways in which inefficient transportation impacts the community.

To foster a culture of innovation and, ultimately, economic development, UMEC has established a process with the Morgan State University Office of Technology Transfer (OTT) to ensure that all research is reviewed for possible intellectual property and commercialization considerations. This dovetails with UMEC's growing emphasis on implementation.

1.1 What are the major goals and objectives of the program?

The major goal of UMEC is to further urban mobility of people and goods in a safe, environmentally sustainable, and equitable manner and formulate new technologies, policies and practices aimed at mobility.

1.2 What was accomplished under these goals?

Below is a chart listing all current UMEC projects; those listed in green are complete, and a final report is available on our website, www.morgan.edu/umec. Those projects listed in orange are complete but are being reviewed by the OTT and will be posted on our website and to the appropriate databases shortly.

Project Type University	Project Name	PIs
Core – MSU	Optimal Automated Demand Responsive Feeder Transit Operation and Its Impact	Young-Jae Lee, Amirreza Nickkar
Core – UMD	Dynamic (Time Dependent) Green Vehicle Routing Problem	Ali Haghani, Golnush Masghati Amoli, Moschoula Pternea
Core – UMD	Evaluating Equity Issues for Managed Lanes: Methods for Analysis and Empirical Results	Cinzia Cirillo
Core – MSU	Hands on Wheel, Eyes on Road	Mansoureh Jeihani
Core – VT	Traffic State Prediction: A Traveler Equity and Multi-model Perspective	Hesham Rakha

Project Type University	Project Name	PIs
Core – MSU	Understanding Access to Grocery Stores in Food Deserts in Baltimore City	Celeste Chavis, Anita Jones
Core – UMD	Optimized Development of Urban Transportation Networks	Paul Schonfeld
Collaborative – UMD, MSU	Optimization of Emergency Traffic Patrols (ETP) Operations	Ali Haghani, Mansoureh Jeihani
Collaborative – VT, MSU	Developing and Testing an ECO-Cooperative Adaptive Cruise Control System for Buses	Hesham Rakha, Hao Chen, Mansoureh Jeihani
Collaborative – VT, UMD	Developing a Connected Vehicle Transit Signal Priority System	Kyoungho Ahn, Hesham Rakha, Young-Jae Lee
Collaborative – MSU, UMD	Innovative Methods for Delivering Fresh Foods to Underserved Populations	Hyeon-Shic Shin, Young-Jae Lee, Paul Schonfeld
Collaborative – MSU, UMD	Shared Bus/Bike Lane Safety Analysis: Assessing Multimodal Access and Conflicts	Celeste Chavis, Cinzia Cirillo
Core – MSU	Driver's Interactions with Advanced Vehicles in Various Traffic Mixes and Flows (autonomous and connected vehicles ACVs) electric vehicles (Evs), V2X, trucks, bicycles and pedestrians - Phase I: Driver Behavior Study and Parameters Estimation	Mansoureh Jeihani
Core – MSU	Sustainable Design of Concrete Bus Pads to Improve Mobility in Baltimore City	Mehdi Shokouhian , Kadir Aslan
Core – UMD	Managing the Impacts of Different CV/AV Penetration Rates on Recurrent Freeway Congestion from the	Gang-Len Chang

Project Type University	Project Name	PIs
	Perspective of Traffic Management	
Collaborative – UMD, MSU	E3: Equity in Evacuation: A Practical Tool and Two Case Studies	Cinzia Cirillo, Celeste Chavis
Collaborative – VT, UMD	Developing an Eco-Cooperative Adaptive Cruise Control System for Electric Vehicles	Hao Chen Hesham Rakha, Cinzia Cirillo
Collaborative – VT, MSU	Improving Public School Bus Operations: Boston Case Study	Youssef Bichiou, Hesham Rakha, Young-Jae Lee, William Eger

1.3 How have the results been disseminated?

In addition to conference presentations and journal submissions, when projects are completed, fact sheets summarizing the research results are sent via email to more than 500 people, including government officials, academics, and professionals in the field. The fact sheets include suggestions for implementation. An annual newsletter, with feature stories about the research, lists all projects.


UMEC
Research Fact Sheet

Figure 1: A one-page fact sheet

All projects are submitted to the national research databases as well as being archived according to our data plan, ensuring they are accessible and searchable.

- The project Hands on Wheel, Eyes on Road created a 5-minute educational, entertaining video about distracted driving and a 23-minute video of a game show about distracted driving for use in various forums and classrooms. View the 5-minute video at https://www.youtube.com/watch?v=cxBP177W06o&t=16s

- The project Understanding Access to Grocery Stores in Food Deserts in Baltimore City has been presented on several occasions:
    - March 8, 2019, at an Institute of Transportation Engineers meeting here at Morgan
    - Oct. 28, 2018 at the University of Maryland Doctoral Seminar
    - Jan. 14, 2019 at the TRB Annual Meeting Presentation with the Baltimore Department of Transportation

Figure 2: Research into food deserts is presented at an Institute of Transportation Engineers meeting.

- Feb. 28, 2019 at the Johns Hopkins University Doctoral Seminar
- Dec. 14, 2018 at the Stakeholder Meetings with Baltimore City Departments of Planning & Health and Lyft
- March 7, 2019 at the WDCSITE Meeting

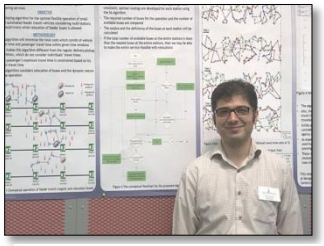


Figure 3: Amirreza Nickkar

- Graduate student Amirreza Nickkar received the 2018 Graduate Scholarship of the Intelligent Transportation Society of Maryland on Nov. 15, 2018. Nickkar presented his study entitled "Phased Development of the Automated Demand Response Feeder Transit System in Rural Areas" at the National Rural ITS and ITS Arizona Annual Conference in Phoenix, Arizona, on October 22. Dr. Lee was the coauthor of this study, which stemmed from the UMEC project *Optimal Automated Demand Responsive Feeder Transit Operation and Its Impact*.

- Three graduate students involved in UMEC research – Samira Ahangari, Istiak Bhuyan and Amirreza Nickkar – and recent Ph.D. grad Dr. Seyedehsan Dadvar were named National Traffic Safety Scholars and attended the 38th annual National Lifesavers Conference on Highway Safety Priorities, March 31-April 2, 2019, in Louisville, Kentucky.

Figure 4: National Traffic Safety Scholars from Morgan State University

- UMEC Director Dr. Andrew Farkas attended the New Mobility Transportation Forum organized by the Baltimore Metropolitan Council on March 13, 2019.

- Representatives from our program will serve on various TRB committees:

Committee Term Name	Committee Name	Committee Nominee Name
2019-2022 AFP50	Standing Committee on Seasonal Climatic Effects on Transportation Infrastructure	Owolabi, Oludare
2019-2022 AP060	Standing Committee on Paratransit	Chavis, Celeste
2019-2022 AP060	Standing Committee on Paratransit	Banerjee, Snehanshu
2019-2022 AND30	Standing Committee on Simulation and Measurement of Vehicle and Operator Performance	Banerjee, Snehanshu
2019-2022 AP045	Standing Committee on Passenger Intermodal Facilities	Franklin, Kristen

1.4 What do you plan to do in the next reporting period to accomplish these goals?

We will continue to ensure that our research projects proceed in a timely fashion. We will work to identify more stakeholders who will collaborate in our research.

For each of the ongoing projects, the researchers have submitted their goals for the next period to UMEC. For example, the project *Developing and Testing an ECO-Cooperative Adaptive Cruise Control System for Buses* will develop the ECO-CACC system and test it in simulation software, and the project *Development of Multimodal Traffic Signal Control* will implement and test the transit signal priority in a connected environment.

2. PARTICIPANTS AND COLLABORATING ORGANIZATIONS. Who has been involved?

2.1 What organizations have been involved as partners?

Boston Public Schools is a partner in research to improve school bus operations.

Maryland Department of Transportation – Maryland Highway Safety Office partnered with UMEC for its research into distracted driving and provided funding.

The Maryland Department of Transportation – Maryland Transit Administration is a partner in the research on shared bus/bike lanes, providing critical data.

Travelers Institute/Travelers hosted a distracted driving event on campus in partnership with UMEC. The Associated Press wrote a story about it https://www.apnews.com/Business%20Wire/0bf26349ba5f444aa0ccc23ed3003c4e

CHART (Coordinated Highways Action Response Team) provided data to test the model for *Optimization of Emergency Traffic Patrols (ETP) Operations*.

UMEC was a sponsor of the International Conference on Demand Responsive and Innovative Transportation Services, Baltimore, MD, April 15-17, 2019.

The Maryland Department of Transportation – State Highway Administration is a prospective collaborator and potential user of *Optimized Development of Urban Transportation Networks.*

The Baltimore City Department of Planning will use the results of the project *Understanding Access to Grocery Stores in Food Deserts in Baltimore City* to develop solutions for those who live in food deserts. The research was presented to Baltimore City's Food Policy Action Coalition, which has 60 members representing nonprofits, universities, businesses, hospitals, farms and residents.

The results of the project *Managing the Impacts of Different CV/AV Penetration Rates on Recurrent Freeway Congestion from the Perspective of Traffic Management* will be presented to the Maryland Department of Transportation – Office of Traffic Safety and shared with the MDOT – State Highway Administration.

The Federal Motor Carrier Safety Administration was identified as a potential funder and collaborator in research; they subsequently toured our labs and met with us about our research capabilities.

2.2 Have other collaborators or contacts been involved?

Dr. Lei Zhang, assistant director of UMEC, made a presentation at the Maryland Quality Initiative Conference. UMEC provided materials for dissemination at the conference.

Dr. Mansoureh Jeihani is the co-chair of the State of Maryland Strategic Highway Safety Plan (SHSP) Distracted Driving Emphasis Area Team (EAT).

Dr. Andrew Farkas serves on the State of Maryland Electric Vehicle Infrastructure Council, established by the state legislature and appointed by the governor.

Dr. Celeste Chavis is a member of the Greater Washington Partnership Equitable Access Workshop; the Greater Washington Partnership created the Capital Region Blueprint for Regional Mobility, a 16-month report that contained proposals and high-level transportation recommendations for Maryland, Washington and Virginia.

3. OUTPUTS: What new research, technology or process has the program produced?

- *Optimization of Emergency Traffic Patrols (ETP) Operations* created a mathematical model that takes into account beat configuration, fleet size and allocation of response trucks. The comprehensive, mixed integer programming model can be used to design freeway safety patrol systems for optimum response while minimizing costs. The model was applied to Maryland's Coordinated Highways Response Team (CHART) and, with minor modifications, could be applied to any location; on a technology readiness scale of 1 to 10, with 10 being ready for immediate implementation, this project is a 9.

- *Driver's Interactions with Advanced Vehicles in Various Traffic Mixes and Flows (autonomous and connected vehicles ACVs) electric vehicles (EVs), V2X, trucks, bicycles and pedestrians - Phase I: Driver Behavior Study and Parameters Estimation* implemented some ACV features in the driving simulator for the first time, which allows for testing of its capabilities and impacts.

- The project *Dynamic (Time Dependent) Green Vehicle Routing Problem* developed more time-dependent green-vehicle routing formulations, and a case study created a network of 150 demand nodes in area roughly the size of Washington, D.C. The model developed can be used by companies to evaluate the effect of green logistic policies such as low emission zones and emission caps on last-mile delivery operations in terms of the changes in fixed cost of fleet acquisition as well as variable operating costs.

- *Optimal Automated Demand Responsive Feeder Transit Operation and Its Impact* developed an optimal routing algorithm specifically for automated demand-responsive feeder transit services, which are fast becoming a reality. The algorithm minimizes total costs and passenger travel time. The outputs would be optimal feeder routings for multiple train stations and feeder buses, as well as the ability to relocated buses to satisfy passenger demand.

- *Evaluating Equity Issues for Managed Lanes: Methods for Analysis and Empirical Results* proposes a methodology that accounts for income effect – the concept that a change in the cost of driving does not impact everyone equally – when appraising managed lanes. Unfortunately, the two methods most commonly used to evaluate proposals like increased tolls and managed lanes assume there is no income effect, which is especially problematic for low-income drivers, who already spend a large part of their income on transportation. This methodology provides a refined tool to appraise the social, economic and equity aspects of managed lanes.

- For the project *Developing a Connected Vehicle Transit Signal Priority System*, researchers developed a Gaussian Process Model and different machine learning techniques to predict bus dwell time at bus stops as well as integrating transit signal priority in a Nash Bargaining traffic signal control algorithm using connected vehicle data. They will develop an advanced CV-enabled TSP algorithm and a connected TSP simulation model which utilizes communication software.

- The algorithm developed for *Development of Multimodal Traffic Signal Control* can be applied to automated vehicle applications to improve mobility and reduce delays at signalized intersections.

- The project *Traffic State Prediction: A Traveler Equity and Multi-model Perspective* developed a novel supervised clustering algorithm for transportation system applications. It also developed a model to identify optimum bike station initial conditions using Markov Chain modeling.

- *Understanding Access to Grocery Stores in Food Deserts in Baltimore City* creates a metric for determining what constitutes a food desert using statistical analyses of surveys and also taking into account public transportation access as well as vehicle ownership.

- AVs will provide a flow of information that can be used to help mitigate traffic. *Managing the Impacts of Different CV/AV Penetration Rates on Recurrent Freeway Congestion from the Perspective of Traffic Management* is developing operational guidelines for highway agencies to take advantage of AV flows in managing congestion. Researchers also are developing a simulation platform to investigate the impact of the AV flows.

- *Innovative Methods for Delivering Fresh Foods to Underserved Populations* is developing a cost-effective and sustainable business model and designing a prototype system model for evaluating various delivery alternatives, such as electric vehicles with connected and automated capabilities, drones, walking, biking, public transit and multi-modal combinations. The project, which uses micro-level conceptual modeling by ArcGIS Network Analysts, will evaluate the model's sensitivity to various pricing and policy options and external factors.

3.1 Publications, conference papers and presentations

- Dr. Cirillo's research into equity in evacuations was featured in Maryland Today on Oct. 26, 2018, "Routes to Safety." (https://today.umd.edu/articles/routes-safety-5e033447-037f-44a5-80e1-569de9c020cf)

- Ahangari, A., Rashidi Moghaddam, Z., Jeihani, M., Chavis, C., Chen, H., Rakha, H., and Kang. K., "Investigating the Effectiveness of an Eco-Speed Control System in the Vicinity of Signalized Intersections Using a Driving Simulator," *98th Transportation Research Board Annual Meeting*, Washington, D.C., January 13-17, 2019.

- Dr. Young-Jae Lee gave a presentation on "AV, CV, EV and Their Applications" in Seoul, Korea, on Dec. 6 for a forum "2018 Global Cooperation: The fast track to smart future" by the Korea Ministry of Trade Industry and Energy and Korea Institute for Advancement of Technology.

Figure 5: Dr. Young-Jae Lee gave a presentation in South Korea.

- Amirreza Nickkar presented the research *Creating a Transit-Inclusive Food Desert Index for Baltimore City* in Charleston, South Carolina, on Feb. 17, 2019.

- Dr. Andrew Farkas presented at Mobility 21: The Second Annual National Mobility Summit of UTCs in Washington, D.C., on April 11, organized by Carnegie Mellon University.

- Ahangari, S., Lee, Y., *GIS Approach to Identify the Potential Service Areas and Feasibility for Demand Response Feeder Transit Service*: US Metropolitan Suburban Areas, in International Conference on Demand Responsive and Innovative Transportation Services, Baltimore, MD April 15-17, 2019.

- Ahangari, S., Jeihani, M., Sheykholmolook, M., *The effect of cellphone usage on driving performance of young drivers using eye tracking in a driving simulator*, Lifesavers National Conference on Highway Safety Priorities, Louisville, Kentucky, March 31-April 2, 2019.

- Dr. Mansoureh Jeihani was a panelist, discussing the *Hands On Wheel, Eyes on Road* research as part of the Travelers Institute Every Second Matters program on distracted driving held at Morgan on April 3, 2019.

- Chavis, C., *Davis, T., *Norris, T., Jones, A. (2018). "An Analysis of Food Accessibility Using the USDA Food Acquisition and Purchase Survey." TRB 97th Annual Meeting Compendium of Papers. Washington, DC. January 7-11, 2018.

- *Managing the Impacts of Different CV/AV Penetration Rates on Recurrent Freeway Congestion from the Perspective of Traffic Management* was presented at the workshop "Risk Analysis for Autonomous Vehicles and Future Directions" on April 26, 2019, at the University of Maryland.

- Huang, A., Chavis, C. (2019) Baltimore Food Policy Initiative, TRB 98th Annual meeting. Washington, DC. January 14, 2019. (invited presentation)

- *Innovative Methods for Delivering Fresh Foods to Underserved Populations* was presented as a poster and in a podium session at the TRB annual meeting in January 2019.

3.2 Journal publications

- The project *Optimized Development of Urban Transportation Networks* has resulted in three journal publications:
    - Jovanovic, U., Shayanfar, E. and Schonfeld, P. "Selecting and Scheduling Link and Intersection Improvements in Urban Networks," *Transportation Research Record,* v2672, Dec. 2018, pp 1-11.

    - Shayanfar, E. and Schonfeld, P. "Selecting and Scheduling Interrelated Projects: Application in Urban Road Network Investment," *International J. of Logistics Systems and Management,* 29-4, 2018, pp 436-454.

    - Peng, Y., Li, Z. and Schonfeld P. "Optimal Development of Rail Transit Networks over Multiple Periods," accepted for *Transp. Research Part A: Policy and Practice,* d Jan. 15, 2019.

- Almannaa, M., Elhenawy M., and Rakha H (2019), "Identifying Optimum Bike Station Initial Conditions using Markov Chain Modeling," *Transport Findings* (doi:10.32866/6801).

- Almannaa M., Elhenawy M., and Rakha H (2019), "A Novel Supervised Clustering Algorithm for Transportation System Applications," *IEEE Transactions*.

- Abdelghaffar, H., Rakha, H., "A Novel Decentralized Game-theoretic Adaptive Traffic Signal Controller: Large-scale Testing," has been submitted for publication to *Sensors Journal*.

- An article is under consideration by the Journal of Simulation Analysis based on the project *Managing the Impacts of Different CV/AV Penetration Rates on Recurrent Freeway Congestion from the Perspective of Traffic Management.*

3.3 Books or other non-periodical one-time publications

- Rakha, H.A., Elhenawy, M., Ashqar, H., Almannaa, M., and Ghanem A. (2018), "Smart Bike-Sharing Systems for Smart Cities," a chapter in *Data Analytics Applications for Smart Cities*.

- A blog written by UMEC Director Dr. Andrew Farkas and posted on the UMEC website, had 40 page views and 35 site visits. Dr. Farkas also had a letter to the editor published in the Baltimore Sun on Nov. 9, 2018, commenting on maglev in response to a long article on the subject.

- The project *Improving Public School Bus Operations: Boston Case Study* created samples of Boston area road link GIS data and road speed data.

- The project *Shared Bus/Bike Lane Safety Analysis: Assessing Multimodal Access and Conflicts* is creating a database of bike facilities that includes the following data for each bike facility roadway segment: facility type, AADT, bus frequency, number of crashes, and roadway speed.

- The project *Understanding Access to Grocery Stores in Food Deserts in Baltimore City* created a database of approximately 500 Baltimore residents' grocery store access surveys which includes information such as mode choice, home location, preferred grocery store, shopping frequency, etc. A database of 13 hack driver interviews (audio and transcribed) is also available.

3.4 Websites or other internet sites

www.morgan.edu/umec In the first quarter of 2019, our website had 553 visitors, who viewed 1,775 pages. Our research pages were the most popular pages. Most of those surfing our site are using a desktop (81%), while 15.7% use a mobile phone and 3.3% use a tablet.

www.facebook.com/urbanmobilityandequitycenter Our Facebook page reaches about 5,500 people each year, and about 2,750 times a year someone likes, shares or comments on a post. As of this writing, 71 people have liked the page. Some posts also appear on our sister page for the National Transportation Center, which has been liked by 165 people and has a similar reach.

Twitter @UMEC research We have 40 followers on Twitter, and increasing that number is a priority for the next several months. Our sister account @NTCMorgan retweets our content.

Instagram: https://www.instagram.com/ntcumec/ We started Instagram last summer, and we have 34 followers.

You Tube:
https://www.youtube.com/channel/UCQ4GSAlNdKTKz6qhWqH1hQA?view_as=subscriber We now have our own channel. The Hands on Wheel, Eyes on Road video was viewed 172 times the first day it was posted.

3.5 Technologies or techniques

- The project *Development of Multimodal Traffic Signal Control* will integrate the developed controller in INTEGRATION, an open-source microscopic traffic simulation software.

- *Hands on Wheel, Eyes on Road* will develop prediction models for distracted driving, which will be useful when targeting educational campaigns and developing safety features.

- *Shared Bus/Bike Lane Safety Analysis: Assessing Multimodal Access and Conflicts* will process video footage to look at the interaction between vehicles and cyclists in shared bus lanes.

- *E3: Evaluating Equity in Evacuation: A Practical Tool and Two Case Studies* applies advanced statistical methods to a transportation problem.

- The project *Developing and Testing an ECO-Cooperative Adaptive Cruise Control System for Buses* is developing ECO-CACC systems for heavy duty vehicles such as diesel and hybrid buses.

- The project *Sustainable Design of Concrete Bus Pads to Improve Mobility in Baltimore City* developed recommendations for the proper design and construction of concrete bus pads to minimize cracking and subsequent repairs, thereby improving mobility of transit vehicles.

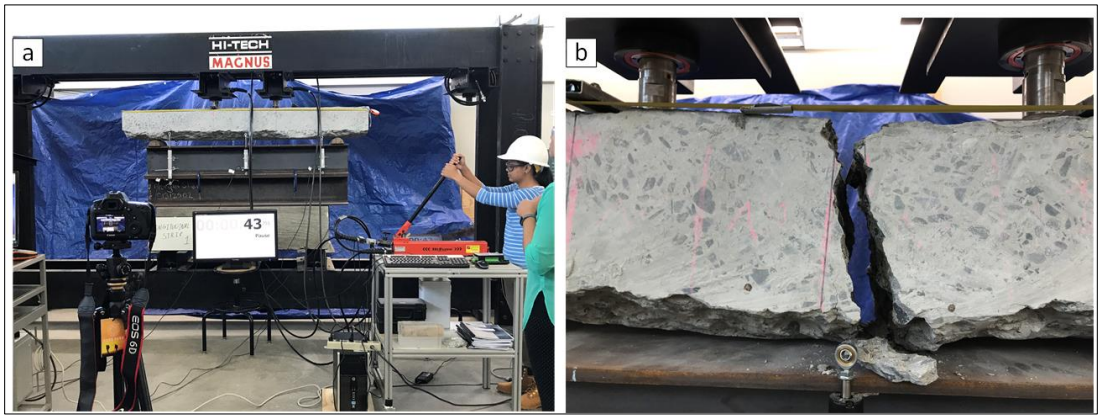


Figure 6: Samples were extracted from concrete bus pads in Baltimore and tested for cracking.

3.6 Inventions, patent applications and/or licenses

- Dr. Mansoureh Jeihani, the principal investigator of the project *Driver's Interactions with Advanced Vehicles in Various Traffic Mixes and Flows (autonomous and connected vehicles ACVs) electric vehicles (EVs), V2X, trucks, bicycles and pedestrians - Phase I: Driver Behavior Study and Parameters Estimation* has been working with the Office of Technology Transfer on patenting code that was written for an earlier non-UMEC project but will be used on subsequent UMEC projects. An application for a provisional patent has been filed.

- Graduate student Snehanshu Banerjee also has a patent application in progress involving extracting data from the driving simulator and data analysis; he developed his idea while working on UMEC research into connected and autonomous vehicles. He expects it will be used in future driving simulator research.

4. OUTCOMES. What outcomes has the program produced? How are the research outputs described in section 3 above being used to create outcomes?

- The results of *Understanding Access to Grocery Stores in Food Deserts in Baltimore City* are being used to develop a transportation access program for residents of West Baltimore in partnership with Lyft.

- Deployment guidance is detailed in the project *Sustainable Design of Concrete Bus Pads to Improve Mobility in Baltimore City*, a field study that involved excavating samples of cracked bus pads and testing them in a structures and materials laboratory. This project's recommendations address both the design and construction methods needed to create more crack-resistant concrete bus pads. Researchers noted a lack of appropriate load identification and definition of critical load scenarios for the appropriate design of concrete bus pads as shortcomings, as well as a design assumption of uniform distribution of soil pressure under the slab. On a technology readiness scale of 1 to 10, with 10 being ready for immediate deployment, this project is a 9.

- The model created in *Dynamic (Time Dependent) Green Vehicle Routing Problem* effectively considers the trade-offs between ICEVs and ECVS under different low emission zones, emission caps and trade policies. It also can be used to find the optimal fleet size and the minimum cost routing plan.

- The second part of the project *Optimal Automated Demand Responsive Feeder Transit Operation and Its Impac*t generated optimal flexible demand responsive feeder transit networks with various unit transit operating costs using the developed routing optimization algorithm and compared the network characteristics of those feeder networks in order to examine the impact of the automated feeder transit operation. With regard to cost, the insight gained from these results is that if unit operating costs decrease, the portion of passenger travel costs in total costs increases, and the optimization process tends to reduce passenger costs more while it reduces total costs. Assuming that automation of the vehicles reduces the operating costs, it will reduce total operating costs, total costs

and total passenger travel costs as well. This study also provides a mechanism for evaluating how efficient automated feeder services are and how they will compare with the fast-approaching automated ridesharing and carsharing services.

- The refined appraisal process for managed lanes developed in *Evaluating Equity Issues for Managed Lanes: Methods for Analysis and Empirical Results* will allow for a more realistic evaluation of how such proposals affect all citizens. Assuming agencies collect data, which is feasible, and use the project's code, this project is at least an 8 on a technology readiness scale of 1 to 10.

- The algorithm and software that will be developed as part of *Developing a Connected Vehicle Transit Signal Priority System* can be used as teaching material in transportation engineering courses.

- The model developed by *Optimization of Emergency Traffic Patrols (ETP) Operations* was tested using data from Maryland and its Coordinated Highways Action Response Team (CHART). The results indicated a significant impact on the performance of the CHART patrol program to reduce incident duration and minimize operating costs.

- As cities allocate limited rights of way to multimodal transportation, more cities are implementing shared bus-bike lanes (SBBLs); however, there is a lack of research on the safety of such facilities. *Shared Bus/Bike Lane Safety Analysis: Assessing Multimodal Access and Conflicts* will provide needed research. Crashes in SBBLs are mostly due to narrow lanes, overtaking, and oncoming traffic. This research will investigate the causes of these accidents.

5. IMPACTS. What is the impact of the programs/ How has it contributed to improve the transportation system: safety, reliability, durability, etc.; transportation education; and the workforce?

- Following the deployment and implementation detailed in the study *Sustainable Design of Concrete Bus Pads to Improve Mobility in Baltimore City* leads to bus pads that last longer, saving cities on maintenance costs and reducing disruptions to mobility in urban and suburban areas.

- The project *Evaluating Equity Issues for Managed Lanes: Methods for Analysis and Empirical Results* promises to impact how proposals for managed lanes are evaluated by governmental agencies, which will create more equitable policy for all drivers.

- Although still in the early stages of modeling and processing data, eventually the project *Improving Public School Bus Operations: Boston Case Study* is expected to help local education departments design school bus routes with better average travel speeds.

- The project *Developing and Testing an ECO-Cooperative Adaptive Cruise Control System for Buses* anticipates improving transit operations by reducing delays and achieving major fuel/energy savings as well as reducing emissions.

- Since some 14% to 18% of accidents are caused by an earlier incident – such as an accident, debris in the road or a broken-down car – reducing the duration of the initial incident is critical to prevent further incidents. *Optimization of Emergency Traffic Patrols (ETP) Operations* improves safety by improving incident response. The model developed for this project enables the design of networks that provide a swift response and coverage where it's needed most. It also could be used for other patrol problems such as snow plows or police cars.

- *E3: Evaluating Equity in Evacuation: A Practical Tool and Two Case Studies* will help local officials efficiently allocate resources during an emergency and optimally evacuate people, especially disadvantaged populations.

5.1 What is the impact on the effectiveness of the transportation system?

- If agencies adopt the recommendations in the project *Sustainable Design of Concrete Bus Pads to Improve Mobility in Baltimore City*, bus pads will last longer and need fewer repairs, reducing costly and congestion-inducing maintenance.

- As adding additional lanes becomes increasingly problematic and expensive, more government agencies turn to managed lanes. *Evaluating Equity Issues for Managed Lanes: Methods for Analysis and Empirical Results* will result in a more just transportation system since it gives agencies the ability to manage such lanes without unduly burdening lower-income users.

- *Improving Public School Bus Operations: Boston Case Study* is expected, through better routing, to reduce tardiness for students.

- Reducing the duration of incidents that cause backups, such as accidents or disabled vehicles, the focus of *Optimization of Emergency Traffic Patrols (ETP) Operations*, will reduce congestion and subsequent accidents.

- Cyclists are vulnerable roadway users. Limited roadway space has resulted in cities creating shared bus-bike facilities to accommodate cyclists and mass transportation. By separating buses and bikes from general traffic, sustainable modes of transportation are promoted. However, it is not clear if this accommodation puts cyclists in harm's way, a question that will be answered by *Shared Bus/Bike Lane Safety Analysis: Assessing Multimodal Access and Conflicts*.

- Grocery store quality and placement is strongly linked to average household income. Residents in lower income areas must spend more money on getting to grocery stores which exacerbates inequities. Areas with a lack of grocery stores are dominated by convenience and dollar stores. Gaps in grocery access can be mitigated in three ways (1) encourage grocery stores to move to food deserts, (2) bring food to residents in food deserts and (3) provide transportation solutions to bring residents to healthy food. *Understanding Access to Grocery Stores in Food Deserts in Baltimore City* addresses the latter two options. It was found that food

delivery services are used more by higher income households, which suggests that providing transportation solutions is the best option to reduce inequities.

5.2 What is the impact on the adoption of new practices, or instances where research outcomes have led to the initiation of a start-up company?

- Two counties in Maryland, Carroll and Anne Arundel, are awaiting the final results of *E3: Evaluating Equity in Evacuation: A Practical Tool and Two Case Studies*.

- The system proposed in *Developing an Eco-Cooperative Adaptive Cruise Control System for Electric Vehicles* can be implemented into electric vehicles to reduce energy consumption and pass signalized intersections.

5.3 What is the impact on the scientific body of knowledge?

- The study *Understanding Access to Grocery Stores in Food Deserts in Baltimore City* found that regardless of vehicle ownership, the majority of residents do not shop at the closest grocery store. Currently, food desert measures (often linked to grocery store incentives) are based on the distance to the nearest store instead of a variety of store options.

- The use of ACV features in the driving simulator for the project *Driver's Interactions with Advanced Vehicles in Various Traffic Mixes and Flows (autonomous and connected vehicles ACVs) electric vehicles (EVs), V2X, trucks, bicycles and pedestrians - Phase I: Driver Behavior Study and Parameters Estimation* provides information about the effectiveness of ACV technology and how well it will be accepted.

- The proposed novel clustering algorithm developed for *Traffic State Prediction: A Traveler Equity and Multi-model Perspective* can be used by other fields.

- The advanced statistical methods used in *E3: Evaluating Equity in Evacuation: A Practical Tool and Two Case Studies* have not seen many practical applications, and the results will help the transfer of basic research to more applied disciplines.

5.4 What is the impact on transportation workforce development?

UMEC research projects engage graduate students by providing opportunities for research in the transportation and engineering fields. All three universities continue to produce high-quality graduates at the bachelor's, master's, and doctoral levels.

- UMEC continues to support two programs in 2019 aimed at workforce development. The highly successful MDOT/MSU Graduate Internship Program is a partnership between Morgan State University and the Maryland Department of Transportation. In recent years, the year-long program has resulted in several students being hired. The Summer Transportation Institute brings high school

students to Morgan for four weeks to learn about opportunities in transportation and engineering and the STEM concepts needed for such work. Although UMEC does not formally follow the students, anecdotally we know of several in recent years who have pursued majors in transportation and engineering.

- The Maryland Department of Transportation Maryland Transit Administration may use the results of *Shared Bus/Bike Lane Safety Analysis: Assessing Multimodal Access and Conflicts* to improve driver training.

6. CHANGES/PROBLEMS.

6.1 Changes in approach and reasons for change.

Nothing to report

6.2 Actual or anticipated problems or delays and actions or plans to resolve them.

- For the project *Developing a Connected Vehicle Transit Signal Priority System*, the TSP algorithm development was delayed due to the complexity of managing connected vehicle data. The researchers are testing various techniques to simplify the data management to finalize the TSP algorithm development.

- The driving simulator test required more effort than originally anticipated, so the project *Developing and Testing an ECO-Cooperative Adaptive Cruise Control System for Buses* received a no-cost extension of the deadline from April 30 to Oct. 30, 2019.

- A micro-level analysis for the project *Innovative Methods for Delivering Fresh Foods to Underserved Populations* took longer than the team had originally planned, delaying the completion by a several months.

6.3 Changes that have a significant impact on expenditures.

Nothing to report.

6.4 Significant changes in use or care of human subjects, vertebrate animals, and/or biohazards.

- Because of the experiences of some participants in the driving simulator, who experienced various degrees of motion sickness, UMEC researchers decided to explore that phenomenon a little further. Although not a UMEC-funded project, the research *Analysis of Driving Simulator Sickness Symptoms: A Zero-Inflated Ordered Probit Approach* gave researchers some valuable insights – and drew quite a crowd at TRB in 2019. Participants in the driving simulator have been offered the use of anti-glare screens and wrist bands for motion sickness to increase their comfort level.

6.5 Change of primary performance site location from that originally proposed

Nothing to report.

7. SPECIAL REPORTING REQUIREMENTS

Nothing to report.