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SOLVING ROADWAY STORMWATER ISSUES AT LESS COST

By Paul Imhoff, University of Delaware

To operate existing roadways and construct new ones, Departments of Transportation (DOTs) and other agencies must meet increasingly stringent regulations for stormwater runoff. For example, to satisfy Chesapeake Bay water quality standards for nutrients and sediment, Maryland State Highway Administration must reduce their emission of nitrogen, phosphorus, and sediment by 75% by 2020. Achieving this milestone is estimated to cost in excess of $720 million using standard technologies, assuming $144k to treat one impervious acre and > 5000 acres to treat. Other states with roadways contributing to the Chesapeake Bay (DE, DC, NY, PA, VA, and WVA) must meet similar reduction goals. In other regions of the country, DOTs must satisfy increasingly stringent stormwater regulations for metals, bacteria, and other pollutants.

Although numerous best management practices (BMPs) exist for stormwater, most require land and significant costs for construction and maintenance. In an ongoing study at the University of Delaware, biochar amendment to roadway soils is being examined to reduce nutrient loading and stormwater runoff volume. Here, the idea is to use existing roadway soils, already owned and maintained by DOTs, and alter them with biochar so that significant stormwater treatment is achieved at modest cost. Biochar is a charcoal-like material formed by combusting waste organic matter, e.g., saw dust, in an oxygen-limited environment. Biochars have high internal porosity and low particle density. Therefore, amending biochar to highways soils is expected to increase total porosity and water retention. Because biochar particles are often large and may enhance the clumping together of soil particles, i.e., soil aggregation, biochar amendment may also increase soil hydraulic conductivity. Finally, biochar amendment is expected to enhance sorption and transformation of nitrogen compounds.

With support from the National Fish and Wildlife Foundation, Transportation Research Board, Delaware Department of Transportation, Maryland Transportation Authority, and City of Charlottesville, VA, biochar was amended at 4% (mass fraction) to a sandy loam in a roadway filter strip along Delaware state highway 896 immediately south of Summit Bridge. Over 74 storm events in 2016/2017, biochar amendment

Left: placement of biochar in top 30 cm of roadway soil (bottom, below dotted line) and control section without biochar (top, above dotted line). Right: four months later after seeding biochar (bottom) and control (top) sections

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reduced average stormwater runoff volume and peak flow rate by 84 and 77%, respectively. In comparison, tillage alone of biochar-free soil reduced average stormwater runoff volume and peak flow rate by 54 and 51%, respectively. Thus, *biochar amendment increased the ability of the tilled roadway soil to reduce stormwater runoff and peak flow rate by ~ 50%*. The reason for the greater stormwater treatment in the field was macropores. Soil macropores in biochar-amended soils accounted for 84% of the flow under saturated conditions. Time-dependent formation of soil aggregates by microbial processes is believed to be the cause of macropore formation, which was enhanced by biochar.

Using costs determined from this field test, 0.12 acres of biochar-amendment is needed to treat 1-acre impervious with approximately 83% removal of nutrients and sediments at a cost of ~ $31,700 per impervious acre treated, a standard metric for assessing BMP performance. A cost analysis comparing biochar-amendment to 23 BMPs indicated that biochar is more expensive than only three BMPs: erosion and sediment control, street sweeping, and urban grass buffers. However, utilization of these BMPs may be limited, for example, because of area of land needed and other constraints like existing slope and buffer width available for urban grass buffers. While biochar costs are similar to an urban grass buffer ($26,600 per impervious acre), biochar-amendment requires a dramatically smaller footprint: 0.12 versus 3.7 acre per impervious acre for biochar and urban grass buffer, respectively. Thus, while these less expensive BMPs should be used where applicable, they are often insufficient to achieve necessary control of sediment and nutrients, in which case biochar-amendment could be used.

Because of the dramatic improvement in roadway soil properties with biochar amendment at this test site, other field tests are planned at locations in Maryland and Pennsylvania. While it is hoped biochar may also increase stormwater infiltration in other locations, the interactions between soil and biochar affecting stormwater infiltration are microbially driven and difficult to predict. Studies are continuing to understand these mechanisms and to provide usable engineering design models for predicting the changes in soil properties with biochar amendment. Acknowledgements: the biochar project included graduate students Joseph D. Brown Sr., Ali Akbar Nakhli, and Sriya Panta; Charles Hegberg, reGENESIS Consulting Services LLC; and Larry Trout Jr., Rummel Klepper & Kahl LLP.

Message from the Director, Chris Meehan

Since the last issue of the DCT newsletter, our faculty, students, and staff have all been engaged in a variety of exciting and transformative activities, as illustrated by the following newsletter articles in this newsletter.

Paul Imhoff and his research group are continuing their studies using biochar amendments in soil to reduce stormwater runoff nutrient loads, a critical need for many agencies striving to comply with clean water regulations. His research is being supported not only by DelDOT, but also the National Fish and Wildlife Foundation, the Transportation Research Board, and the Maryland Transportation Authority.

The Civil and Environmental Engineering department recently expanded with a number of new faculty hires. You can find a brief introduction to these assistant and associate professors on the following page. We are excited that some of this new growth is occurring as the result of our new Construction Engineering and Management degree program; stay tuned for more developments in this area in the future.

Additional work by UD researchers from the Institute for Public Administration outlines the establishment of crowdsourcing tools for the public to use to enhance accessibility of DART bus stops. These include online map-based tools to share accessibility experiences walking, biking, or rolling to, or from, a DART First State bus stop location in Delaware.

Continued next page

Our center's research scientist, Mingxin Li, describes his work on optimization of snow plow routes so that DelDOT can meet its performance objectives of clearing snow and ice from roadways within a specified interval based on the amount of precipitation. This project clearly illustrates how research can directly impact highway maintenance operations by reducing costs and improving the vehicle fleet configurations. A timely article as the fall weather gets colder and the winter season approaches!

The format for our next newsletter will be significantly different and we hope you like it. As always, we welcome suggestions, comments, and your input.

Center for Integrated Asset Management for Multi-Modal Transportation Infrastructure Systems (CIAMTIS)

University of Delaware is pleased to be part of the team selected by the U.S. Department of Transportation to serve as the Region 3 University Transportation Center known as the Center for Integrated Asset Management for Multi-Modal Transportation Infrastructure Systems (CIAMTIS). In addition to the University of Delaware, the team, led by Pennsylvania State University includes George Mason University, Lehigh University, Morgan State University, Penn State University – Altoona, Virginia Tech, and West Virginia University.

CIAMTIS will focus on three themes: 1) Application of innovative materials and technologies, 2) Condition assessment and health monitoring of existing infrastructure, and 3) Infrastructure management and innovative financing. While specific research projects will be developed through proposal projects, funding at UD is expected to support one graduate student fellowship and some modest education and outreach projects. The education and outreach projects include partial support for ArtsBridge (Lynnette Overby), the Annual Interuniversity Symposium on Infrastructure Management (AISIM) and the Advanced Infrastructure Management Bootcamp. Stay tuned for more details!

Two previous UTCs have been funded at UD and three UTCs are currently funded at UD:

- From 2006 to 2013 UD led a Tier 2 center focused on Resiliency of Transportation Corridors;
- From 2012 to 2016 we were part of the Center for Advanced Infrastructure and Transportation (CAIT) led by Rutgers as a Tier 1 Center;
- From 2013-2018, UD has been a consortium member of the National Center at Rutgers.
- From 2014 to 2019, UD has been part of the Mid-Atlantic Transportation Sustainability (MATS) UTC – the Region 3 center led by University of Virginia.
- Since 2016, UD has partnered with University of Nevada and Virginia Tech as a Tier 1 University Transportation Center on Improving Rail Transportation Infrastructure Sustainability and Durability.

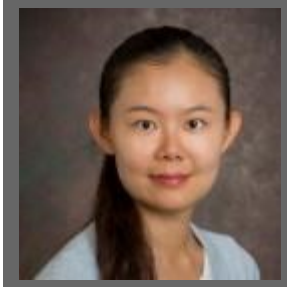
NEW FACULTY

The Department of Civil and Environmental Engineering have some new faces this fall. We are pleased to introduce them to you along with a faculty member who joined the department in 2017. Included after the introductory paragraph is a link to their profile on the department's website, which lists their contact information on campus and publications.

Mark Nejad

Dr. Nejad is an Assistant Professor who joined the department in January 2017 and brings with him expertise in the areas of autonomous and connected vehicles, electric vehicles, sustainable transportation, interdependent infrastructure systems, operations research, network optimization, cloud computing, and game theory. Dr. Nejad received his Masters and Doctoral degrees from Wayne State University. Since joining us from the University of Oklahoma, he has been busy building his research group and research portfolio. His wife, Lena Mashayekhi, is also at the University of Delaware in the Electrical and Computer Engineering department.
http://www.ce.udel.edu/people/faculty-profile/?id=22

Ri Na



Dr. Na is one of the new faculty members hired in the department's Construction Engineering and Management program. She completed her undergraduate work in her native China and then a Masters and Doctoral degree in Construction Engineering and Management at the University of Oklahoma. Her specialties include building information modeling and its applications in sustainability, high-performance buildings and envelopes, and computational fluid dynamics (CFD) using BIM models.
http://www.ce.udel.edu/people/faculty-profile/?id=202

Jovan Tatar

Dr. Tatar, Assistant Professor, joins the Civil Engineering faculty from the University of Louisiana at Lafayette. His research interests include advanced materials for sustainable and resilient structures, repair and retrofitting methods, reinforced and pre-stressed concrete, bridge engineering, durability of building materials, fracture mechanics, and multiscale materials characterization. Dr. Tatar's graduate degrees were conferred by the University of Florida. Since his brief time on campus he has been working with the Research Office to submit several proposals to build his research program.
http://www.ce.udel.edu/people/faculty-profile/?id=205

Monique Head

As a new Associate Professor in the department, Dr. Head is returning to her alma mater having received her undergraduate and Masters degrees at UD. She joins the department from Morgan State University where she had an active research program in the areas of civil infrastructure systems and bridge engineering and design. Welcome back to campus, Professor Head.
http://www.ce.udel.edu/people/faculty-profile/?id=206

New Crowdsourcing Tools Invite Input on Accessibility to/from DART First State Bus Stops

Marcia S. Scott, IPA Policy Scientist

Transit riders may use a WikiMap (https://bit.ly/2IDIfRs), Geoform (https://bit.ly/2tWMa6L), and/or GIS Crowdsource Story Map (https://bit.ly/2IGWY51) to provide input on first- and last-mile accessibility experience to a DART First State transit stop in Delaware.

Whether it's a bus trip to/from work, shopping, or home, public transportation rarely stops directly in front of a passenger's origin or destination. Barriers to transit ridership often include "incomplete" streets that lack safe, connected, and well-maintained infrastructure for pedestrians, bicyclists, and persons with disabilities; or bus stops that lack amenities such shelters, lighting, signage, and proximity to intersections with crosswalks. Transit riders accessibility to, or from, a bus stop often described as the first- and last-mile transit experience.

The Institute for Public Administration (IPA) at the University of Delaware has collaborated with the Delaware Transit Corporation (DTC), which operates DART First State Transit, to develop three map-based crowdsourcing tools on first- and last-mile bus stop accessibility in Delaware.

Crowdsourcing involves the use of web- and mobile-based applications (apps) to obtain information, insight, and knowledge from the public. DART First State transit riders may use one, or all three, of the online, map-based tools to share a first- and last-mile accessibility experience walking, biking, or rolling to, or from, a DART First State bus stop location in Delaware. All crowdsourcing tools—including a Wikimap, Geoform, and GIS Crowdsource Story Map—are publicly available on the Mobility in Motion website (www.MobilityDE.org). The crowdsourcing tools are not designed to report a critical roadway condition that should be addressed immediately (such as a crosswalk signal malfunction). Those issues should be referred to the Delaware Department of Transportation (DelDOT) Transportation Management Center (operating 24/7/365) at 302-659-4600, #77 via cell, or through e-mail at deldottmc@state.de.us.

The three crowdsourcing tools are part of an outreach and engagement strategy for a statewide Mobility in Motion initiative. Public input and data will be gathered to identify public transit and human services transportation barriers, challenges, and gaps in services in Delaware. The information will be used to develop a Coordinated Public Transit—Human Services Transportation Plan, or "Coordinated Plan," for the State of Delaware. The Coordinated Plan will serve as a strategic framework for addressing the state's existing and future mobility needs. Information collected from the crowdsourcing tools will help to identify needed bus stop accessibility improvements related to pedestrian and bicycle infrastructure, ADA accessibility, and connectivity.

In addition to the crowdsourcing tools that are gathering input from DART First State transit riders, in-person outreach is being conducted throughout Delaware at community events, public workshops, and meetings of groups that represent transportation-challenged populations. A Needs Assessment Survey is being also conducted until September 30, 2018. All Delawareans (whether or not they ride transit) are invited to take the survey, which is available in both English (https://bit.ly/2IwCWDd) and in Spanish (https://bit.ly/2MvhPnl).

DCT Hosts 15th Annual Research Showcase

The Delaware Center for Transportation (DCT) hosted its 13th annual transportation research showcase on Wednesday, May 9, 2018 at the University of Delaware's Paradee Center in Dover, Delaware. The showcase offered the opportunity for project investigators and graduate students to display posters and share progress on research projects to DelDOT representatives and other interested parties. Showcased were currently funded projects in the areas of environment, pavement & materials, planning, soils, bridges & structures, plus traffic and intelligent transportation systems (ITS). This year we welcomed visitors from various transportation agencies which included: DelDOT; Federal Highway Administration; Davis, Bowen & Friedel; Duffield Associates; Jacobs Engineering; McCormick Taylor; Pennoni and Wallace Montgomery. A light lunch was served and of course back by popular demand, ice cream from the University's UDairy Creamery was offered in a variety of flavors. For additional photos, please visit our website: https://sites.udel.edu/dct/2018/06/04/research-showcase-2018/

Toolbox Showcases Traffic-Calming Techniques in Delaware

Marcia S. Scott, IPA Policy Scientist

The Institute for Public Administration (IPA) at the University of Delaware has crafted new visual content on traffic-calming techniques within its online *Delaware Complete Communities Planning Toolbox* (www.completecommunitiesde.org) Adobe Spark pages, videos, and infographics are designed to foster an understanding of strategies to plan and design for complete communities in Delaware. New topics within the *Toolbox,* with high-impact visual content include:

Road Diets

While roads have been engineered to move more cars faster and quicker, streets without safe places to walk, cross, catch a bus, or bicycle put people at risk. Delaware has one of the highest per-capita pedestrian fatality rates in the nation. IPA's new Adobe Spark page within the *Toolbox* (https://bit.ly/2mYv9pw) illustrates how a safety-focused roadway alternative called a Road Diet can make more room for other uses or modes—such as walking or biking—by removing travel lanes from a roadway. The Spark page embeds videos that animate the benefits of Road Diets, curb extensions, and streetscaping elements. Project examples include Claymont's Philadelphia Pike, Wilmington's Washington Street extension, and Wilmington's Union Street.

Pop-Up Demonstration and Pilot Projects

Transforming a street into a vibrant cultural corridor in Wilmington, converting a vacant space into a pocket park in Middletown, calming a neighborhood road with a pop-up traffic circle in Newark, and testing a pop-up buffered bike route as part of a Safe Routes to School project; Pop-up demonstration and pilot projects are growing in popularity as a way to collaboratively engage community members to temporarily transform and co-create high-value, low-cost public spaces—including streets. A new Adobe Spark page (https://bit.ly/2vhcrNC) showcases several successful community-driven, pop-up demonstration projects which have sparked community pride, economic revitalization, safer streets, pedestrian/bicyclist improvements, and placemaking benefits in Delaware.

A "Stories of Delaware's Complete Communities" video series features innovative pop-up, traffic-calming projects on IPA's Complete Communities YouTube Channel (https://bit.ly/2KqOp9g).

Parklets

In Delaware, a Wilmington neighborhood and the municipalities of Georgetown, Seaford, and Newark are transforming on-street parking spaces into seasonal or portable parklets. Parklets are extensions of the sidewalk from the curb into the street that include installations of public seating, art, plants, platforms, and other elements that replace several on-street parking spaces, either permanently or temporarily. IPA's new Adobe Spark page (https://bit.ly/2mXiaEI) shows how parklets in Delaware are becoming vibrant gathering places that are attracting people, reenergizing commercial districts, and calming traffic.

LET US KEEP YOU INFORMED

If you wish to continue to receive updates on DCT and T2/LTAP events, newsletters, technical bulletins and educational training workshops enter and/or update your contact information here.

Engineering and Policy Researchers Study Equity in Baltimore's Bike Share Program

By: Philip Barnes

Cities across the United States are embracing bike sharing as an essential public service and quality of life enhancer. Bike share systems typically involve fixed docking stations strategically positioned within the urban environment. Each docking station can house multiple bicycles and users pay a fee to check out a bicycle for a fixed amount of time, eventually returning the bicycle to another docking station. Bike share usage is popular among residents, commuters, and visitors. At the end of 2016, 55 cities in the United States had docking-style bike share systems with a total of 42,000 bikes in operation (National Association of City Transportation Officials, 2018). Advocates frequently cite sustainable benefits of these systems such as improved public health, lower carbon emissions, reduced traffic congestion, and economic development (Shaheen, Cohen, & Martin, 2013).

Yet bike share programs are not beyond criticism. The most common critique levied against bike share is that the systems serve a narrow segment of a city's population while failing to reach other individuals, some of whom may already experience mobility challenges. For instance, research shows that bike share users are predominately white, non-Hispanic, highly educated, males, high-income earners, and the employed (Buck et al., 2013; Goodman & Cheshire, 2014; Shaheen, Elliot, Chan, Cohen, & Pogodzinski, 2014; Smith, Oh, & Lei, 2015; Ursaki & Aultman -Hall, 2015). Others argue that biking in general, and bike share systems in particular, are responsible for gentrification and displacement of longtime residents (Hoffmann, 2016; Rodriguez, 2017). This raises questions of bike share fairness and equity – an often overlooked aspect of sustainable urbanism (Agyeman, 2013; Mercier, 2009).

In 2016, Baltimore, Maryland joined other cities across the United States by launching its own bike share system with then Mayor Rawlings-Blake announcing that the new program was a critical part of the city's "network of sustainable transportation options" (Campbell, 2016). Almost

Existing (Black) and planned (white) Baltimore Bike Share docking stations.

immediately, there were charges of an ill-conceived and inequitable public service program with racially-charged claims that Baltimore's "bike-share perpetuates [the city's] transit apartheid" (Kinney, 2016). Researchers at the Institute for Public Administration collaborated with civil engineering faculty at Morgan State University to answer two straightforward questions about Baltimore's new system. 1) Does the Baltimore Bike Share program mirror other cities' systems and narrowly serve the mobile, wealthy, educated, white urban elites, or are the benefits more broadly distributed to larger demographic groups? 2) If bike share injustice is present, what can be done to ameliorate this undesirable condition?

Continued next page

Their research, funded by the Mid-Atlantic Transportation Sustainability University Transportation Center (MATS UTC) offers a dual-perspective evaluation of equity in Baltimore Bike Share that is akin to supply-side and demand-side analytic orientations. The first approach, which is a Geographic Information System (GIS) -based equity gap analysis, developed a population density normalized Bike Equity Index to quantitatively assess the spatial distribution of the City's bicycle infrastructure supply and how it serves (or doesn't serve) Baltimore's transit-dependent and environmental justice communities. The second analytic orientation, which applies a user and barrier analysis, utilizes focus group and survey data to identify the low equity groups and the variables that limit (or don't limit) their demand for the City's bike share program. When combined, the two perspectives – one top down and the other bottom up – present a more comprehensive picture and nuanced understanding of the current system's equity performance. The combined full analysis offers deeper insights into opportunities for Baltimore Bike Share improvements to enhance equity.

The research team's findings demonstrate that Baltimore Bike Share infrastructure is unevenly distributed across the city's many communities and is under-supplied in areas with transit-dependent residents. Furthermore, the results support claims of a demographic mismatch between current bike share system users and the general population. The communities underrepresented among Baltimore Bike Share users are less educated, lower-income, non-whites, Hispanics, and females. The survey research indicates that females express concern over certain barriers to accessing and using Baltimore Bike Share, such as knowing how to use the system, personal safety, helmet use, harassment, and hygiene. No significant barriers were identified for the other underrepresented demographic groups.

To enhance the equity of the system, the research team recommended that the City of Baltimore prioritize bike share system expansion into the neighborhoods east (Franklin Square, Lexington) and west (Washington Hill, Butcher's Hill, Highlandtown) of the Downtown corridor. A robust community outreach strategy that targets underrepresented populations is also recommended and should include initiatives such as a grassroots bike share ambassador program and organized community rides. The research team also notes that bike share docking stations can be leveraged for their advertising potential -- since most people learn about the system by first seeing the stations on the street -- and should contain marketing materials that speak directly to underrepresented communities. The full analysis and research report will soon be available on the MATS UTC website.

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RESEARCH

As each project is completed, a final technical report will be available on the DCT website: http://www.ce.udel.edu/dct.

As of the publication of this newsletter, results of the FY19 Research Program solicitation had not been announced.

IRIB Ongoing Structural Health Monitoring

The Indian River Inlet Bridge represents a significant investment in infrastructure for the State of Delaware. This funding supports ongoing evaluation of the bridge and preservation of its state-of-the-art structural health monitoring system. Ending 8/31/2019

Principal Investigators: Michael Chajes and Tripp Shenton, *Department of Civil and Environmental Engineering*

Project Manager: Jason Arndt, *Bridge Design*

Field Measurement of the Dynamic Impact Factor for Buried Culverts

This research is aimed at field investigation of the actual dynamic load effects on buried culverts. The final product is expected to be a refined methodology for estimating the impact factor for buried culverts. Ending 11/4/18

Principal Investigator: Kalehiwot Manahiloh, *Department of Civil and Environmental Engineering*

Project Manager: Ping Jiang, *Bridge Section*

Evaluation of New Data Sources for Planning and Operations FY18

This project will provide DelDOT a demonstration of what some new sources of cell phone data can provide for information and how it would be useful for both operations and planning. Ending 5/31/19

Principal Investigator: Rusty Lee, *Department of Civil and Environmental Engineering*

Project Manager: Michael DuRoss, *Division of Planning*

FY18 Regional Travel Demand Modeling Support

Assist DelDOT with developing, maintaining, applying and evaluating its travel demand forecasting model that is used not only by DelDOT but also by the state's two metropolitan planning organizations. Ending 5/31/19

Principal Investigator: Rusty Lee, *Department of Civil and Environmental Engineering*

Project Manager: Michael DuRoss, *Division of Planning*

2017 DelDOT Municipal Agreements Project

The goals of this project are for student interns to conduct a careful review of all known agreements that exist between DelDOT and Delaware municipalities, documenting the boundaries of the agreement and its applicability to roadways systems. Ending 12/31/18

Principal Investigator: Rusty Lee, *Department of Civil and Environmental Engineering*

Project Manager: Karen Brittingham, *Division of Planning*

Fall 2016 and Summer 2017 Processing of DelDOT-TMC Bluetooth Data for Travel Time and Speed Measurements

This project entails transforming raw Bluetooth data into a useable form for DelDOT and processing the data into average time and speed between sensors and comparing average speed with posted speed limit to get an indication of delay. Ending 8/31/19

Principal Investigator: Ardeshir Faghri, *Department of Civil and Environmental Engineering*

Project Manager: Mark Eastburn, *Division of Planning*

Statewide Traffic Data Analysis and Evaluation – FY17

Analysis and evaluation of potential methods for the TMC and for Division of Planning for testing and implementing improvements to measurement of travel speeds and congestion, which are key elements of prioritizing projects. Ending 12/31/18

Principal Investigator: Rusty Lee, *Department of Civil and Environmental Engineering*

Project Manager: Gene Donaldson, *Traffic Management Center*

Exploratory Field Monitoring of Pile Downdrag

The goal of this project is to measure field data related to the performance of installed deep foundation elements that are used to provide structural support for bridges. Ending 12/31/18

Principal Investigator: Christopher Meehan, *Department of Civil and Environmental Engineering*

Project Manager: Jason Hastings, *Bridge Section*

Developing Methodologies to Convert Time of Day Person Schedules to Travel Demand Model Inputs for Evaluation of PRT System Designs

Develop the methodologies for a student trip table and faculty/staff trip table that may consist of multiple O-D tables or other methods determined to be best for modeling purposes. Ending 6/8/19

Principal Investigator: Rusty Lee, *Department of Civil and Environmental Engineering*

Project Manager: Michael DuRoss, *Division of Planning*

(Continued on page 11)

Innovative Applications and Utilizations of TMC Data

The aim of this project is to thoroughly review the data collected by the Traffic Management Center, test its accuracy and reliability and as part of the final deliverable, provide a table detailing what units of DelDOT can use the TMC data. Ending 6/8/19

Principal Investigator: Ardeshir Faghri, *Department of Civil and Environmental Engineering*

Project Manager: Mark Eastburn, *Division of Planning*

Using "Big Data" to Enhance the Transit Planning Process and Transit Users' Experiences

The focus of the research is to better understand how current and prospective transit users are able to use and respond to transit system operations through technology, social media, and "big data"-type resources. Ending 6/8/19

Principal Investigator: Mingxin Li, *Department of Civil and Environmental Engineering*

Project Manager: Jaren Kauffman/ Bruce Allen, *Division of Planning*

Latest Innovative Approaches to Intra-agency Skill-Based Resiliency for DelDOT

The main objective of this research is to evaluate the most recent developments in the area of skill-based resiliency. Strategies most appropriate for the unique context of DelDOT will be listed and ranked. Ending 6/8/9

Principal Investigator: Mingxin Li, *Department of Civil and Environmental Engineering*

Project Manager: Jaren Kauffman/ Bruce Allen, *Division of Planning*

Evaluating Biochar Amendment of DNREC Biosoil-14 Bioretention Medium

As a follow-up to field tests, this project will evaluate the performance of DNREC Biosoil-14 (standard DNREC bioretention mix) with and without biochar amendment on nutrient removal and plant growth. Ending 12/31/18

Principal Investigators: Paul Imhoff, *Department of Civil and Environmental Engineering*

Mingxin Guo, *Delaware State University*

Project Manager: Sara Esposito, *Maintenance & Operations*

Fall 2017 and Summer 2018 Processing of DelDOT-TMC Bluetooth Data for Travel Time & Speed Measurements

The main purpose of this project is to process and analyze the Bluetooth data collected by the Traffic Management Center for travel time and speed measurements throughout the state. Ending 8/31/19

Principal Investigator: Ardeshir Faghri, *Department of Civil and Environmental Engineering*

Project Manager: Mark Eastburn, *Division of Planning*

On-Call Development and Logistics for Video Analysis of Intersections and Roadways for Planning and Evaluation

This project aims to further develop software, hardware, and processes to gain observational insights into our transportation system from the use of multi-spectral imaging and other remote sensing technologies. Ending 12/31/18

Principal Investigator: Chandra Khambhamettu, *Computer and Information Sciences*

Project Manager: Paul Moser, *Division of Planning*

Snow Plow Route Optimization in Delaware

By Mingxin Li, Arde Faghri, Dian Yuan, Wanxin Li, Qiuxi Li

Roadway snow and ice control is one of the most complex and fascinating venues for routing applications. The primary problems involved in winter road maintenance planning and operation procedure include defining a service level policy, locating depots and assigning arcs to sectors, routing service vehicles, scheduling vehicles, and configuring the vehicle fleet. Over the years, a substantial body of research on various aspects of snow and ice control has been created, the majority of it focuses mainly on managing snow and ice operations during the winter months. Figure 1 illustrates a typical Salt stockpiles and equipment in Delaware. DelDOT is able to

Figure 1: Salt stockpiles and equipment

(Photo taken on January 4, 2018 Smyrna, DE)

track its plows on the interactive map on the agency's website or on its app available for Android devices and the iPhone during snow storms (Figure 2).

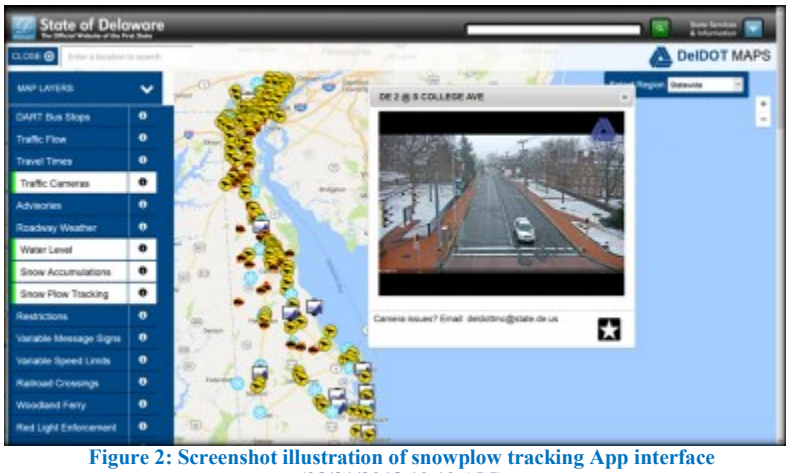

Figure 2: Screenshot illustration of snowplow tracking App interface (03/21/2018 10.10 AM)

The goal of this research project is to develop a model for optimizing snow plow routing in order to be as effective as possible while meeting DelDOT's performance goals with the maximum efficiency: roadways clear and passable within 24 hours after the end of the snowfall when snowfall is less than 4 inches; between 4 and 8 inches, 48 hours; over 8 inches, 72 hours. The results will then be used by DelDOT to ensure that all primary road links are serviced and total operational costs are minimized.

ArcGIS is one of the most widely used platforms with integrated collection of GIS software products. ArcMap, the main component of ArcGIS, has abundant sophisticated tools for spatial analysis, geographic data management and building maps. In addition, ArcGIS platform has a good scripting and model builder. ArcMap Network Analyst provides network-based spatial analysis tools for solving complex routing problems. One of the essential functions of Network Analyst toolset is the Vehicle Routing Problem solver. The VRP solver's goal is to develop optimized routing solution by minimizing the overall operation cost for the fleets. The VRP solver is developed based on Tabu search metaheuristic. It's a method for mathematic optimization. The structure of the GIS-based snow plow route optimization method is described as a flowchart in Figure 3.

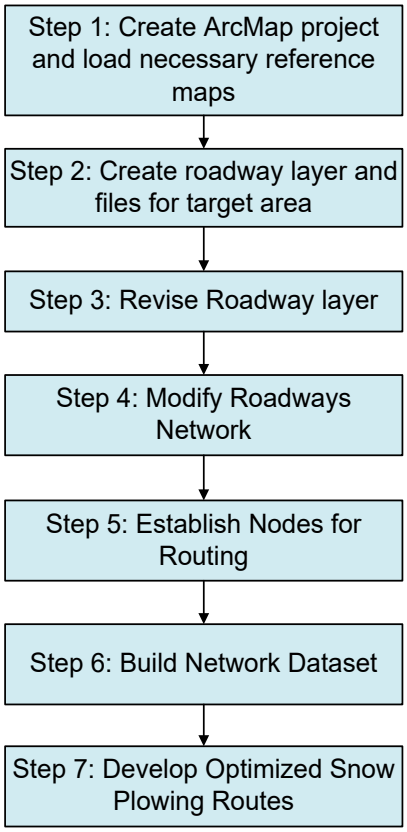

Figure 3: Flowchart for GIS-based snow plow route optimization

A basic vehicle routing problem (VRP) usually presents a node-to-node routing problem, but our snow plow routing problem is a network covering problem. To convert snow plow routing problem to a basic VRP, some elements are added to the network. Before solving snow plow routing problem with VRP solver, some preprocessing are needed for establishing a proper GIS map, such as road classification, number of lanes, alignment correcting intersection modification, etc. Based on the DelDOT Snow Book, the snow plow classification information has been added to GIS map's attribute table as a new field.

According to the DelDOT Snow Book, there are two major models of snow removal trucks – 6-wheelers and 10-wheelers. To solve the routing problem, for several sectors, tests were taken within two scenarios. For example, according to Snow Book, there are three 6-wheelers and two 10-wheelers serving Area 5, Sector D. As mentioned, in the first scenario, both 6-wheelers and 10-wheelers could be assigned to serve low-class roadways (Figure 4). In the second scenario, 10-Wheels snow-plowing trucks are only assigned to serve the primary and secondary roads; 6-Wheels snow-plowing trucks are assigned to serve other classes of roads – tertiary, suburban and reimburse.

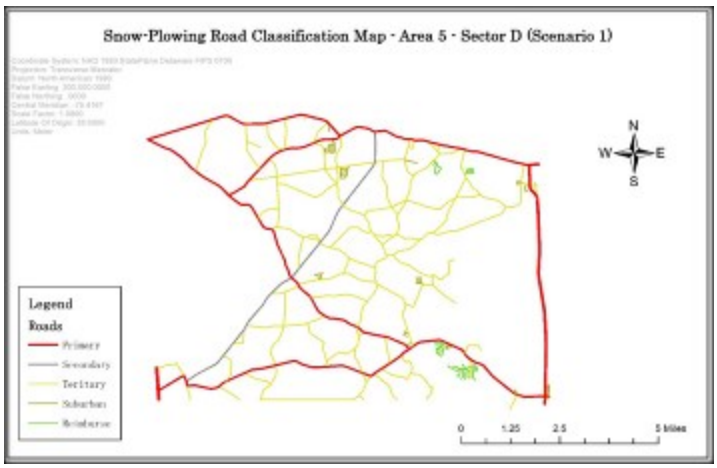

Figure 4: Example for scenario 1

Figure 5 presents the routing problem solution for two 10-Wheels trucks.

The GIS-based method provides a visually based route optimization tool that may be utilized by DelDOT highway maintenance personnel who perform snow and ice control activities. The GIS data and maps are processed for running routing solution. The model is able to create optimized snow plow routes for three counties in Delaware, as well as provide the total cycle times for completing each route. The method is examined repeatedly for different areas under different scenarios. GIS-based analyses were conducted to not only derive snowplow routing strategies using the proposed methodology, but also draw useful conclusions for winter road maintenance agencies. The research team summarized the results of tasks and incorporated the resultant insights and findings and described how to apply various modeling tools for snow plow route optimization analysis.

Scott Presents on Road Diets at Women in Transportation Conference

Marcia S. Scott, Policy Scientist with the Institute for Public Administration (IPA) in the School of Public Policy & Administration (SPPA), recently presented at the 2018 Women in Transportation Seminar (WTS) annual conference in San Diego, Cal. The panel session, *Road Diets: Why You Aren't Losing, only Gaining* highlighted how local, regional, and state transportation agencies are putting their roads on "diets" by reducing street widths and vehicle lanes to reallocate space for pedestrians and bicyclists. More than a safety countermeasure, these traffic-calming measures can encourage active transportation, support place-based economic development, foster high levels of civic pride and engagement, and create healthy and environmentally friendly travel options.

Scott's presentation showcased visual tools within IPA's online *Delaware Complete Communities Planning Toolbox* (https://www.completecommunitiesde.org/) that feature best-practice examples of road diets and traffic-calming measures in Delaware (see: https://goo.gl/b3qCu8). The session was moderated by Rebecca Crowe, transportation specialist with the Federal Highway Administration's Office of Safety. Panelists included Wendy Cawley, P.E., traffic safety engineer with the City of Portland, Oregon and Morgan Beryl, senior transportation planner with the Tahoe Regional Planning Agency, Nevada.

Founded in 1977, WTS is an international organization dedicated to the professional advancement of women in transportation. WTS is comprised of 6,500 members, 79 chapters, and is connected to a network of 40,000 transportation professionals.

The mission of the Delaware Center for Transportation is to improve the movement of people, goods, and ideas, and be viewed as a valuable resource for transportation-related issues and challenges within the state, the mid-Atlantic region and beyond.

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