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Fiscal Year 2019-20 Annual Research Program Highlights
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Directors’ Message

We are pleased to present the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center’s Annual Report for research projects ending within the 12-month period from July 1, 2019 to June 30, 2020. During this period, the AHMCT Research Center also conducted several other research projects that continued beyond this period and therefore will be discussed in future annual reports. In this reporting period, the AHMCT Research Center continued its deployment-focused research, while also beginning to address operational challenges of COVID-19.

The AHMCT Research Center, established in 1991, investigates application of advanced technologies including sensing, communications, information and computer networks, automation, and robotics to highway maintenance, construction, and operations. The overall goal is to improve the safety of workers and the traveling public, while also addressing efficiency of operations, reliability of infrastructure, and impact on the environment and the traveling public. The emphasis of recent research has been on the development or evaluation of human-centric systems and software, i.e. systems where humans play a key role in their control or utilization. The Center has also been developing methodologies for digital transformation of project delivery and integration of Virtual Design and Construction and Civil Integrated Management for the California Department of Transportation (Caltrans).

The AHMCT Research Center is recognized worldwide as a leader in development of advanced technologies for transportation infrastructure applications, and deploys about two integrated prototype machines, devices, systems, or software applications each year into California Department of Transportation (Caltrans) operations for detailed beta testing, which ultimately leads to continuing Caltrans use of the developed technology. In this process, the AHMCT Research Center has developed extensive experience in lining up its research and development work towards achieving Caltrans’ mission. This includes work on GPS/INS (Inertial Navigation System) integration and other sensing and on-site evaluations which has included successful projects providing significant cost/benefit in areas including Mobile Terrestrial Laser Scanning, Advanced Transportation Management, Asset Management, Remote Sensing and Communications, GPS/GIS sensing and visualization and COZEEP/MAZEEP applications. AHMCT maintains an intense focus on deployment and commercialization, key issues for our research partner, Caltrans. Our in-depth understanding of Caltrans methods, needs, equipment, and personnel is a significant asset in all of our research. Currently the AHMCT Research Center is also looking into the future and considering application of Artificial Intelligence (AI), Zero Emission and Autonomous Vehicle as well as modern Driver Assist technologies for applications in Caltrans-type operations.

Bahram Ravani and Ty Lasky
Co-Directors, AHMCT Research Center
Spotlight on Maintenance Research

Task 3176: Research to Support Crack Cleaning Operations in Moving Lane Closures

**Problem:** Caltrans maintains roughly 10,000 miles of longitudinal pavement edge joints with Asphalt Concrete (AC) shoulders. Sealing these longitudinal joints (also referred to as cracks) takes priority over other types of crack sealing operations since 75% of water and debris will enter the pavement structural section along these edges. The maintenance required to seal these cracks is often an expensive budget item, but when properly applied, good seals produce great cost benefits to Caltrans in the form of reductions in concrete spalling and extending the interval between major shoulder rehabilitations. Caltrans’ common crack cleaning practices, such as compressed air and wire wheels, fail to remove packed debris or rooted vegetation. Cutting methods such as routing provide extraordinary crack cleaning results but are labor intensive.

**Goal:** This research examined and identified innovative longitudinal pavement edge joint cleaning and preparation strategies for use in moving lane closure operations. Through this research, conceptual designs and methods focusing particularly on the incorporation of commercially available and customizable equipment were developed. Design concepts included preliminary deployment implementation and operational plans.

**Methodology:** The research approach began with a review of commercially available equipment and methods used for crack cleaning operations. A Caltrans Technical Advisory Group (TAG) was established early in the project. AHMCT and the TAG worked collaboratively during the research to guide the research effort. The proposed work aimed to investigate methods of mechanizing crack routing/cleaning processes to address the common problems (slow speed, labor intensive, and worker exposure) associated with crack routing/cleaning. The focus was on router cleaning and perhaps vacuuming and air blasting tools to clean cracks. The outcome is a proposed conceptual design and detailed specifications of equipment and methods enabling Caltrans Maintenance to increase the efficiency of longitudinal crack cleaning operations, especially in high production, moving lane closure highway operations. System design emphasized near-term development and pursued off-the-shelf components or equipment to streamline the potential future building of the design.
The joint crack cleaning machine project also included the development of an appropriate guidance system. In the case of longitudinal joint cracks, the guidance scheme had to be capable of tracking a void potentially packed with debris and vegetation at a continuous moving closure speed up to 3 mph. The first phase of the guidance development was a laboratory-based proof-of-concept demonstration. The second phase of guidance system development focused on tracking actual pavement joint cracks.

**Conclusions:** The main deliverable for this research project was a detailed design of a high production joint crack cleaning machine capable of single pass longitudinal joint crack cleaning at a continuous target speed of 3 mph. The machine was also designed to be capable of operation in a moving lane closure to ostensibly support Sealkal operation.

The second technology development was to demonstrate an effective PCC slab edge tracking system. A semi-automated guidance system was developed where a system operator can supervise the router operation and switch as necessary between manual and automated tracking control modes. This research succeeded in developing and demonstrating a small-scale automated joint crack identification and tracking system mounted on a rolling hand-cart.

**Benefit:** This research resulted in the development of innovative technologies that improve the quality of longitudinal edge joint preparation methods and tools available to Caltrans maintenance crews to apply the highest quality seals possible on the highway. Maximizing joint seal service life through improved cleaning and preparation methods enables Caltrans to maximize the benefits of joint sealing including reducing concrete spalling, increasing the interval between major shoulder rehabilitations, and realizing level of service paybacks. Additionally, reductions of worker exposure through faster operations, extended maintenance intervals, and increased in-vehicle operations maximizes worker safety, a key Caltrans goal.
Task 3608: Research to Integrate Color and Thermal Imaging IR Cameras with Caltrans 3D-GPR and GNSS/INS System

**Problem:** Caltrans Geophysics and Geology Branch has received four Strategic Highway Research Program (SHRP2) grants that incorporate implementation of 3D-GPR (ground-penetrating radar) and thermal IR imaging non-destructive evaluation (NDE) technologies for Caltrans. Working with the Caltrans Division of Equipment, the Geophysics and Geology Branch integrated a commercial off-the-shelf (COTS) 3D-GPR system with a precision COTS Global Navigation Satellite System/Inertial Measurement Unit (GNSS/IMU) position and orientation system. AHMCT assisted Caltrans in the software and electronics integration between the 3D-GPR and the Applanix GNSS/IMU position and orientation system.

The SHRP2 grants provided limited funds for procurement of thermal IR imaging camera hardware for the Caltrans 3D-GPR vehicle. However, the SHRP2 grants were insufficient for design and integration of the IR camera with the 3D-GPR vehicle and the GNSS/IMU positioning system.

**Goal:** The primary goal of this research was to improve Caltrans' ability to inspect pavement and bridge decks through use of thermal IR sensing and data processing by providing an integrated vehicle sensing platform which can collect data while the vehicle is moving at highway speeds, eliminating the need to close lanes or slow traffic.

**Methodology:** The AHMCT Research Center examined and identified innovative IR and color or B/W cameras based on previous research results, recommended the best candidates, and supported integration of these cameras into the existing Caltrans 3D-GPR vehicle. The design and implementation methods incorporated commercially-available and customizable equipment and software. This task was performed collaboratively with the Caltrans Geophysics and Geology Branch. AHMCT provided the equipment specifications for Caltrans Geophysics and Geology Branch to perform the hardware and software procurement. AHMCT purchased COTS camera and related systems in support of evaluation and recommendation development. Caltrans purchased actual cameras, enclosures, and systems to be integrated with the 3D-GPR vehicle. AHMCT performed the system integration. The integrated vehicle was field tested by Caltrans.

**Conclusion:** The key deliverables of this project were:
1. Developed Infra-red (IR) Imaging and Polarized Visual Imaging (PVI) camera requirements for pavement distress detection.

2. Completed system integration of three-dimensional Ground Penetrating Radar (3D-GPR), GNSS/IMU system, computer, power electronics, IR and PVI cameras.

3. Completed camera mount design, fabrication, and installation.

4. Completed fabrication and installation of custom 3D-GPR antenna storage system for the mobile data collection vehicle.

5. Supported Caltrans deployment of the data collection vehicle in pilot projects.

SHRP2 recognized the utility of thermal IR for early identification of shallow-seated deterioration in pavements and bridge decks. Early detection allows for repair and rehabilitation ahead of significant degradation, saving maintenance time and money. Through this research, Caltrans has now installed a thermal IR system on its 3D-GPR vehicle, allowing georeferenced visual and thermal IR imaging of pavement and deck surfaces concurrent with 3D-GPR imaging of the subsurface.

**Benefit:** This research directly supports Caltrans’ Strategic Goal of Stewardship and Efficiency as it supports consistent application of thermal IR data collection and processing for improved infrastructure inspection and maintenance. The research also supports Safety and Health as it allows thermal IR data collection from a moving vehicle, keeping workers off the pavement. The research supports System Performance as data collection will be at highway speed, eliminating traffic impacts, and will enable improved inspection and maintenance of critical infrastructure, including bridge decks.

Finally, currently no other DOT possesses the unique, combined capability of mobile 3D GPR and thermal IR imaging. Thus, this research particularly contributes to the Caltrans Organizational Excellence strategic goal by continuing and enhancing Caltrans’ national leadership in the application of NDE methods for highway infrastructure.
Spotlight on Equipment Research

Task 2730: Evaluation of Remote Control Mowers for Roadside Management

**Problem:** Caltrans currently uses tractors and gang mowers to manage roadside grasses and vegetation. Vegetation control is needed to prevent or reduce the severity of roadside fires, provide sight distance, and for aesthetics. In areas not accessible to the mowers, workers on foot use string trimmers to complete the work, with associated risks from working on steep slopes with hand tools. The nature of the work can expose workers to traffic and may pose risk of vehicle rollovers to workers operating machinery on steep slopes.

**Goal:** This research evaluated Caltrans-acquired remote control mower (RCM) systems to determine their ability to improve worker safety in roadside vegetation control operations. Preliminary research indicates that RCMs show the potential to increase worker safety by reducing workers' exposure to traffic and decreasing injuries due to vehicle rollovers.

**Methodology:** To confirm the expected benefit, AHMCT evaluated RCMs for roadside management. This included evaluation of the Alamo RCMs recently acquired by Caltrans. AHMCT also evaluated the Green Climber, an RCM from a second company, which was rented for the evaluation period. The research included obtaining information directly from Caltrans operators, direct observations of field operations, and a cost-benefit analysis.

The initial testing objective was to define the operational capabilities of RCMs within Caltrans slope mowing operations. Evaluating the effectiveness of the machines included measurements of mowing rates and other factors. Testing and evaluation were focused on the Traxx, which Caltrans has acquired and operated during Season 1 and Season 2. A second mower, the Green Climber LV600, was tested in Season 2.
Conclusions:

1. The research identified substantial promise for Caltrans use of RCMs. There are clear conditions, e.g. slopes and confined areas, where RCMs will be far more effective than conventional mowers (CMs) or string trimming. Initial quantitative mowing rate comparison was provided.

2. The use of CMs is significantly more cost-effective than the RCM or a worker with string trimmer for most Caltrans roadside mowing.

3. RCM use costs less than string trimmer operation. The lower cost and reduced hazard exposure of personnel justifies the use of the RCM instead of workers with string trimmers when possible. Due to cost reduction, the RCM can be substituted in many string trimmer operations. In cases of removing brush, the RCM will likely be very effective. Additional unquantified benefits can be expected due to a corresponding reduction in physical injuries and exposure to traffic.

4. Using an RCM to mow the steep sloped area of the average interchange will increase the associated mowing cost of mowing an interchange by approximately 30%. However, regular use of an RCM to mow slopes will reduce tip-over accidents. Mowing the steepest slopes cannot be done with CMs, and operators may be tempted to mow at the limits of the CM. If RCMs are used regularly, the CM operators will be less likely to operate at the limits of the CM. This will reduce tip-over accidents, which will reduce injuries and associated costs.

Benefit: Key contributions of this research project include:

- Provided an understanding of the slope mowing challenge by defining the typical slopes found along roadsides.
- Defined the limits of CMs and the areas where RCMs will be more capable.
- Provided estimates of mow rates.
- Defined important factors that affect mowing rates on roadsides.
Spotlight on Operations Research

Task 2970: Vision-based Sensor System for Site Monitoring: Wrong-Way Driving, Phase 1

Problem: Wrong-way driving (WWD) can result in accidents and injuries and is a major safety concern. In California, WWD on state highways kills or injures numerous Californians each year, and collisions caused by WWD are more likely to result in fatal or serious injuries than other types of collision. According to the California Highway Patrol (CHP), from 2001 to 2014 a total of 193 fatal collisions and 685 injury collisions occurred on state highways in California because of WWD. Wrong-way collision rates in the first half of 2015 were unusually high, resulting in several fatal accidents in the Sacramento and San Diego areas. These wrong-way collisions were, as usual, deadly.

Goal: AHMCT’s research objectives for this task included:
• Collect off-ramp traffic volume data over the day at regular collection intervals.
• Capture and evaluate WWD events on exit ramps included in the study.
• Determine the number of wrong-way events before and after mitigation.
• Determine when most of the wrong-way events occur.
• Determine the percentage of wrong-way drivers who turn around and exit back down the same exit ramp.
• For any commercial wrong-way detection systems installed by Caltrans during this research, determine how well these systems perform in terms of detection as well as successfully turning a wrong-way driver back.
• To the best extent possible, assess factors that can be contributing causes of wrong-way events.

Methodology: A Vision-Based Site Monitoring (VBSM) system was developed and installed on ten exit ramps in Sacramento and two exit ramps in San Diego to capture video of WWD incidents in order to observe WWD driver behaviors and achieve the noted research objectives. The solar-powered VBSM system consisted of a solar panel, solar battery charger/Power-Over-Ethernet (PoE) power supply, two batteries, a camera, and a cellular data modem. VBSM systems were mounted on a wooden pole, and camera analytics software detected WWD events and captured short video clips of all WWD events. The camera analytics also collected traffic volume data.
Conclusions:

1. The data suggests that for a given exit ramp, the likelihood of a WWD event is higher during the hours when the traffic volume is lower. This matches with the literature, which found that wrong-way movements tended to originate from points with low land-use density and in places and times with low traffic volume.

2. Approximately 35% of the WWD events captured were due to wrong-way travel on a one-way street, followed by direct entry to the exit ramp.

3. The events tended to be in the early morning hours, i.e. from about midnight to 6 am (56% of events in study).

4. The ratio of WWD events for daytime to nighttime was approximately 1:2.

5. The exit ramp configuration, e.g. exit onto a one-way street or signage on approaching streets, seems to have a significant influence on the number of WWD incidents.

6. Time of day was also observed to play an important factor based on representative ramp volume patterns. During commute hours (typically Monday - Friday, 7-9 am and 3-6 pm), ramp volume is higher, so that the (possibly confused) WWD vehicle operators may have a better chance of correction since a WW driver can see more cars coming in the opposite direction. Also, lighting is typically better in these periods. Because of these combined factors, the likelihood of WWD events as well as potential severity of such events are viewed as significantly reduced.

7. The collected data indicate that WWD events are spread throughout the week, and throughout the day.

8. The collected data also indicate that there is a higher concentration of WWD events in the midnight to 6 am period, which is consistent with a connection to DUI. However, the data collected over approximately three years indicates that driver confusion, in general, appears to be a more significant factor in WWD events.

9. The collected data indicate that most drivers (85%) recognize their WWD error fairly quickly, and turn around or otherwise correct their driving before they enter the freeway. This helps to explain the difference in some of the results of this research vs. the previous literature that only considered WWD events leading to collisions.

10. For the Sacramento mitigated exit ramps, the WWD event rate dropped from 3.0 events/ramp/year before mitigation to 1.4 after mitigation, a 53% drop in the rate of wrong-way events. Such a significant drop seems to be a strong indicator of the effectiveness of the mitigations selected and installed by Caltrans.

Benefit: The completed research provides substantial benefits to Caltrans and the traveling public. Assessing the baseline magnitude and frequency of the wrong-way driving problem is key to evaluating any future improvement in this important traffic safety area. In addition, the scientific, measurement-based approach taken in the study allows Caltrans to make informed, data-driven decisions regarding future detection and/or mitigation strategies based on their known effectiveness as demonstrated in this study.
Task 3178: Developing a Strategic Roadmap for Caltrans Implementation of Virtual Design Construction/Civil Integrated Management

Problem: Virtual Design and Construction (VDC) and Civil Integrated Management (CIM) are emerging paradigms. Together VDC and CIM can enhance project delivery while also enriching the data available to Maintenance and Operations. CIM promotes the reuse of data throughout the entire lifecycle of the project thus reducing the need for redundancy. Caltrans has some aspects of VDC/ CIM already implemented but for maximum impact these must be part of a comprehensive plan. It is anticipated that integrating VDC/CIM into Caltrans organization will lead to increased efficiencies and enhanced safety. In order to integrate VDC/CIM technologies into Caltrans an understanding of the current status within the organization as well as the state of technology will be needed. A high-level strategic roadmap is also required to guide the allocation of resources.

Goal: The objective of this research was to create a high-level strategic roadmap that shows an overview of the current state of Caltrans, the gaps, and the known best practices. It is anticipated that this roadmap will assist with high-level decisions regarding how resources be most effectively allocated for the purpose of enhancing and integrating Caltrans VDC/CIM practices. Ultimately these decisions are expected to result in higher quality outcomes.

Methodology: The methodology of this research included conducting high-level surveys, interviewing stakeholders, conducting literature reviews, and synthesizing the gaps uncovered. As a starting point, an online survey at Caltrans was used to measure the current status of VDC/CIM tools as identified in NCHRP 831. The survey results were used to identify potential strengths and weaknesses as well as to identify areas where more in-depth conversations are needed. More in-depth interviews with specific individuals and stakeholders were conducted as needed. Individuals also expressed their views on obstacles and difficulties that may pose a challenge to achieving VDC/CIM. In order to understand the best practices, a literature review was conducted that leveraged existing resources to collect information that had been publicly shared previously. Given the current state of Caltrans and the known best practices, gaps were identified. The results of the above work was then used to
generate a high-level strategic roadmap for Caltrans to help guide integration of VDC/CIM within Caltrans.

**Conclusions:** The results of this work generated a detailed roadmap for VDC/CIM integration as well as tables summarizing gaps and next steps. The roadmap provided action items and intermediate milestones/objectives. A large body of work remains in determining the how and when. Managers must look beyond the application of VDC/CIM technologies and implement other elements of VDC/CIM to complete cultural and institutional change for VDC/CIM integration.

**Benefit:** The results of this work identified relative strengths within Caltrans as well as areas where there is opportunity for improvement. Summaries of gaps between Caltrans current practices and the known best practices have been tabulated.
## Active Research Task Summary

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