The University of Melbourne

White Paper on Transport Safety in the Era of Digital Mobility

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Introduction

While remarkable progress has been made with technological, operational and behavioral improvements in the century-old, automotive-based transport systems used around the world, rapid technological changes are occurring that could amount to a reset in outcomes for transport users. The convergence of connectivity, automation, electrification and on-demand services suggests a transformation in transport safety, community access, traffic efficiency, emissions and energy use. A new era of digital mobility is being catalyzed by vehicle automation and connectivity coupled with new mobility services and business models. Widespread deployment of connected vehicle (CV) technology is an important enabler of automated vehicles (AVs).

This is a global phenomenon. A new and expanded industrial ecosystem is growing up around AVs, with established and new players, fast-moving developmental partnerships, collaborations, and acquisitions. These partnerships require timely support in terms of test facilities, deployment pathways, analytics and public policy development. While AV deployments will increasingly play out on public roads, less familiar markets are also arising in cities, helping to propel technologically-driven “smart city” innovations.

Safety – of vehicles, drivers and roadway infrastructure – has been a central topic of transport research, management and operations for many decades. The advent of AVs raises important new safety issues. Safety is often quoted as a compelling reason to accelerate the deployment of AVs: with more than 90 % of serious crashes attributed to driver error (1), AVs could significantly reduce crash risks. However, early versions of AV may be subject to technical lapses and unforeseen issues in interacting with conventional vehicles. And undue reliance on automation may tend to distract a highly-developed transport safety management enterprise from the relentless attention needed to create a “safe system”.

Automotive and Intelligent Transportation System (ITS) markets are world-wide. The rapid development of connected and automated vehicle (CAV) technologies stretches the ability of educational, research, standards and infrastructure organizations to keep up. No one country is able to unilaterally cover the myriad operating conditions, cases and scenarios applicable to AVs. And the scope of the vehicle-driver-infrastructure system is expanded with communication technologies, vast amounts of data and system security considerations.

The University of Melbourne (UoM) created the Australian Integrated Multimodal EcoSystem (AIMES) for implementing and testing emerging connected and automated transport technologies at large scale in a complex urban environment. While these technologies have broad social and economic implications, and AIMES addresses this broad canvas, safety is treated as the most urgent issue. A Summit sponsored by AIMES, and held in Melbourne on October 1 – 2, 2018 provided a global perspective of digital mobility research and development, bringing together Australian stakeholders from government, industry and academia, leading safety practitioners covering vehicles, drivers and infrastructure, and including those involved in development and deployment of digital mobility. This White Paper summarizes the key points of discussion and opportunities for research collaboration.

Avenues to Accelerated Learning

2.1 Research Collaboration via Memorandum of Understanding (MOU)

The Australian Government, represented by the Department of Infrastructure, Regional Development and Cities, and the Government of the State of Michigan signed a Memorandum of Understanding (MOU) at the Summit. They agreed to enhance cooperation between their respective government bodies, knowledge based institutions, clusters, and businesses in transport research, technology, entrepreneurship and innovation, reflecting their desire to accelerate potential social and economic benefits for future generations and vulnerable sectors of society around the world.

The MOU recognizes that:

- Research, technology, entrepreneurship and innovation are fundamental to economic growth and prosperity;
- International collaboration is mutually beneficial to respective transport and educational institutions, researchers and businesses; and
- There is a need to strengthen respective abilities and accelerate the commercialization of emerging technologies and the growth of domestic firms.

The Summit heard that Michigan has led other U.S. states in deploying vehicle-to-infrastructure communication (V2I), trials of truck platooning, trials of traffic signal priority for emergency vehicles, smart signage and legislation for the testing and operation of AVs on public roads. At the same time, a significant network of automotive R&D centres and academic research institutes is carrying out research based on extensive deployment of promising technologies. These research efforts include purpose-built off-roadway test facilities for AVs (Mcity and the American Center for Mobility (ACM)) directly supporting collaboration by industrial consortia and the development of third party standards by organisations such as the Society of Automotive Engineers (SAE) who are noted for their globally-adopted levels of automation.

2.2 Significance of CAV Test Beds

Test beds for CAV technologies have been developed in a number of countries, and are suitable for the distinct technologies of CV as well as AV. The growing number of test beds includes off-roadway facilities as well as specific corridors and zones on public roads. The AIMES test bed encompasses a dense, complex six-square-kilometer section of inner-city Melbourne on the edge of the Central Business district. AIMES provides sensing, connectivity and analytics for a wide range of mobility players – including cars, buses, trams and pedestrians – and for key elements of the infrastructure, such as signalized intersections. Illustrating the variety of test beds, the Queensland CAVI Program focuses on the use of Dedicated Short Range Communication (DSRC) to provide safety applications for cars and trucks, and with special attention to Vulnerable Road Users (VRUs). These applications are aimed at crash avoidance, using a tailored approach to crash types prevalent in Southern Queeensland, but also of great relevance throughout Australia.

The Summit also heard how the Michigan off-roadway facilities – Mcity and the American Center for Mobility (ACM) – are highly-complementary to on-road corridors and areas like the Ann Arbor Connected Vehicle Test Environment (AACVTE). One of the greatest AV challenges is the development and certification of automated driving systems (ADSs) suitable for safe operation in more-and-more-general operating environments. This requires the development of third-party professional standards, such as those developed by SAE, providing AV definitions and safe design principles. While CV test beds tend to be located on public roads, AV test beds include off-roadway facilities as well as specifically-declared public road locations.

2.3 Self-Certification of Automated Driving Systems

Building upon SAE standards for AVs, the U.S. National Highway Traffic Safety Administration (NHTSA) has released Version 3.0 of its guidance for AVs, (2) including voluntary safety assessment carried out by manufacturers. Recognizing the enormous complexity of vehicle operating environments, the guidance establishes the concepts of a manufacturer-declared Operational Design Domain (ODD) and a Safety Evaluation Report. Recommended means of AV testing encompass simulation, off-roadway testing and on-roadway testing.

Current work undertaken by the National Transport Commission (NTC) recognizes the merits of a similar self-centification approach for AVs in Australia. It is likely that the Australian self-certification for AV safety will be mandatory (unlike the U.S. where it is currently voluntary).

The core Australian working group visited Detroit and Ann Arbor on January 15-17, 2019 and conferred with key Michigan players in transport research, innovation, standards and policy. Technical tours facilitated by the Michigan Economic Development Corporation (MEDC) led to several points of research connection. A productive focus for the group's activities will be: the safety and mobility of the transport *system* comprising a full range of modes, including cars and trucks.

Safe Digital Mobility

CAV represents the leading edge of the conversion from analog to digital in our transport systems. Digital systems are irresistible for their speed and economies of scale, and cities are developing integrated mobility platforms. Such platforms not only use real-time information about conditions in transport networks (including roads) but also utilise information about user preferences. While safety remains fundamental, it can no longer rely on upfront single-domain standards, nor post-evaluation (such as crash analysis). Just as digital decision-making occurs in unpredictable real-time, a real-time concept of operations ("conops") is needed to take care of safety. The conops includes the vehicle, but goes beyond to the infrastructure and the network.

3.1 "Safety Baggage" With CAV

The Summit discussed several of the "digital quandaries" compounding the safety potential of CAVs. First and foremost, we are all concerned about the quality and reliability of ADSs and new types of safety risks with ADSs that may mislead, shut down and exclude the human from driving and crash avoidance. This concern stands in stark contrast to the notion that ADSs will eventually bypass the types of human error that cause the majority of serious motor vehicle crashes. We seem to be uncomfortable with the idea that vehicle automation is a "safety feature" when that safety feature may be inconsistent and cannot be subjected to a generally-accepted test. The long-standing statistic of more than 90 % of serious crashes involving human error (1), does not imply that AVs will avoid this percentage of crashes.

A further critical example is distraction of drivers and other mobility participants such as pedestrians. As we are drawn into a continuous process of digital interaction and discourse, we find it inceasingly difficult to devote ourselves to a single task. Digital mobility systems present us with an increasing number of real-time possibilities and decisions, requiring our immediate attention. Automation may then be viewed as an essential aid to our on-going digital activities, but can it be relied upon?

Finally, safety becomes inseparable from security in that the quality and reliability of the ADS is highly dependent on the cybersecurity of the ADS and its communications regimes. Given that security is strongly linked to data privacy, and generally correlates with less privacy, safety is further subject to system-level decisions ("settings") that are not transparent to the user.

3.2 Safety Management Including CAV

Safety remains the "first among equals" when considering the potential benefits of AVs. While the prevention of more than 90 % of serious crashes is an unattainable AV goal for the foreseeable future, it is likely that a majority of such crashes could be avoided in a "fully-evolved future". Nevertheless, the significant safety issues to be addressed along the way to a CAV-oriented mobility system may not be amenable to conventional notions of risk management: we need to first learn about the unusual risks posed by CAV. Further, the stakes are high for the safety management of CAVs: loss of trust in AVs would in itself pose a significant risk to our ability to realise the AV route to safe mobility. Therefore, research that helps us learn about the early-stage risks of AVs is an essential step to unlocking the large safety potential of AVs.

Australian road safety policy, like many other countries, adopts the "Safe System" approach which accepts that drivers are error-prone and creates a more forgiving road and vehicle environment through engineering and technology, and also through greater acceptance of responsibility at higher levels of design and management. Intense safety programs conducted by public sector safety professionals need to continue and not be diluted by the promise of "crash free" technology.

It is important to recognize that digital mobility raises the stakes for the "safe system" to absorb risks because users are not only error-prone but also highly-engaged in real time, and early ADSs may be unreliable. At the same time, the possibilities for providing a safe system expand considerably with the advent of CAV. Most significantly, the safe systems process is accelerated and costs much reduced when physical solutions may be replaced by digital measures. The early-stage possibilities for CV in its own right should be fully recognized. The Summit's discussions lead to an unmistakeable sense that the fastest, broadest evaluation of ADSs, and the use of digital solutions by managers of infrastructure and traffic, will do much to perpetuate safe systems.

3.3 Scenarios With Connected, Automated, Electrified Vehicles (CAEVs)

Scenarios investigated by Infrastructure Victoria (3) show that the benefits of connected, automated, electrified vehicles (CAEVs) extend “across the silos”, and encompass impacts on traffic congestion, greenhouse gas emissions, Gross State Product (GSP), road accidents, vehicle operating costs, health, mobile networks, roads, and energy networks. It was found that 97 % of Victorians would be better off, and modest investments would be needed in the road network. Modest investments are also needed in IT and energy networks.

This study is both insightful and comprehensive. Even if only some of its findings prove pertinent to Victoria’s future, digital mobility has huge change potential and deserves realistic attention by policy-makers. The study well captures the risk-reward potentialities with CAV, with large upside and considerable downside: “automated and zero emissions vehicles may be the biggest shift since the car itself. With a potential change of this scale, a lot of uncertainty is to be expected”.

Transport Research Disrupted

A great deal of CAV research to date has been safety research, in combination with broader considerations of supporting policy, technological deployment and user behavior. At the same time, transport researchers across a broad spectrum of disciplines – including human factors, traffic modelling and analysis, travel behavior, economics, public transport, energy and emissions – have incorporated aspects of CAV in their research.

The resulting impact of CAV on the field of transport research emerged in breakout discussions of research questions. While these discussions were focused on a number of domains of technological influence (eg. freight movement), the research questions collectively reveal a small number of high-level imperatives for Australian transport research. These imperatives are partly created by the advent of CAV, but also give societal meaning to the technological era of transport.

4.1 Impacts of AV, CV, and CAV on Safety Research

The totality of U.S. – and in some respects global – transport research is represented in the vast activities of the U.S. Transportation Research Board (TRB). CAV has had a pervasive effect on TRB's transportation programs, as evidenced in (4). Safety of CAV is overtly represented in certain activities, but is less obviously represented in many other programs. For example, studies of CAV legal and liability issues have an underlying safety rationale. Safety has long been a cornerstone of transport research and this will continue in the digital era.

Safety research began to change with the "naturalistic studies" of recent decades, where technologies were introduced – and data collected – in vehicles driven by real drivers in their day-to-day trips. In the U.S., Australia and elsewhere, these studies extended for many months and millions of miles of data were collected detailing driver behavior with, and without, the subject technology. This human-centred research approach remains valid today. It enabled us to study near-crashes, rapidly-advancing our ability to study fast-moving trends in human behavior such as mobile phone use, and distraction in general.

To remain relevant in the digital world of rapid technological and human-use changes, research has moved from a linear, predictive model to a cyclical model. If use cycles are created to be big enough to address a significant piece of the market, and small enough to avoid unintended consequences, it is possible to learn quickly and move to the next cycle. Therefore, we now see more and more demonstrations, test beds, and model deployments. CAV product development may be carried out in the same environments where sensors are widely deployed, data is generated and researchers and students are active.

In the case of off-roadway test centres for AVs, a common base of test elements and scenarios is going to be needed. Researchers who are active in such centers will have the opportunity to collaborate with other globally-distributed centres and standards bodies in developing test elements and associated data protocols for AVs. Those with existing naturalistic databases upon which to base test elements have a strong advantage.

The Summit was reminded that CV is not a bespoke technology and is deceptively impactful. Researchers need to embed themselves in CV learning cycles and understand the contribution of CV in its own right to system safety. CV data is critically important for analysis by researchers, even more so because AV data is highly-proprietary. The density of CVs in the traffic stream is an important variable, and it appears that even small numbers of CVs have an impact on traffic behavior.

Data is critical to researchers. Pooling and sharing of data from diverse CV environments are important. This type of sharing does not naturally occur and MOUs should be used to help bring this about. The Australia-Michigan MOU provides an important vehicle for CV data pooling and sharing.

4.2 Research Questions Discussed

Public, Multi-Modal, Active Transport

The emotional state of travellers – often distressed and distracted in their current trips – is an important influence on safety. If travellers have more choice, the stress reduces. Multi-modal systems enabled by data, including the use of more personalised information, are needed; connecting public transport vehicles to other road vehicles will improve both safety and efficiency. A continuum of transport is needed from "personal", through "shared" to mass transit.

This will allow a high-level operating picture to be created sooner, before all the moving parts are connected. AIMES is already working on important questions such as:

- What is the data requirement and how is it brought together?
- How do we access what currently exists? and
- How do we get individuals to opt-in and provide personalized information?

Active transport goes beyond pedestrians and cyclists to include e-scooters and e-skateboards. How do these devices connect with mass transit? Vehicle information should be shared with all others, including public transport and active transport participants.

Digitalisation and Data for all Users

There is a need for the exchange of a minimum AV data set for the purposes of mapping and trip planning. A distributed means of communicating, analyzing and sharing data is needed, covering trip planning, mapping and navigating construction zones. Significant security and privacy questions surround data ownership and access, personal vs. public data, trusted processes, and data value and protection. Public vs. private roles and fear of data being used for enforcement are also important issues.

It was strongly recommended that a long-term approach is needed based on active community involvement and active listening. The creation of high community awareness, an opt-in mobility platform, and data exchange and brokerage are needed to encourage community involvement with AV and CV technology in an advanced real-time mobility system.

Safety Evaluation of AVs

Summit discussion of AV safety included involvement in world-wide safety protocols as well as local testing, research and outreach capabilities. It makes sense to have a global model of AV safety evaluation methods. This may include terminology, manufacturer guidance and operating environments. Discussion centred on a combination of global protocols combined with local validation. So-called "edge cases" – highly-unusual events with a long return time – should be shared across regions, along with testing methods and testing technology. However, local test tracks are needed for the purposes of industry engagement with public agencies and research institutions, and for "safe conversation" across the AV ecosystem. There is a responsibility to provide a local environment for AV testing and development as well as determining AV compliance. Key local uses cases also need to be defined.

The use of standard terminology will help in explaining AV safety more widely. What is the minimum performance standard for AVs? Should there be independent testing of AVs, perhaps for insurance purposes, or under safety rating schemes such as the New Car Assessment Program (NCAP)? What kind of AV learning framework may be needed so that driving machines may be updated and artificial intelligence (AI) improved? Virtual AV testing environments are needed. The Summit heard that simulation is used extensively in Michigan, in support of test tracks and on-road testing. User education will be needed, and high-capacity test facilities such as Michigan's ACM could provide such training services.

Initiatives in Education and Policy

A common language is needed for educating the public about AVs. This is a critical issue and best practice approaches are needed, including understanding the public's views and concerns. Along with a better appreciation of AV benefits and issues, it is important for the public to have realistic expectations. From a safety perspective, we should make better use of existing technologies, educate the public on existing safety systems and show how AV is a progression from those existing technologies.

There is a need to work across government and industry "silos", to ensure that the necessary funding is made available and efforts are fully-coordinated. Agreements between government and industry are needed to support research into:

- User training and appreciation of safety features;
- Baseline understanding of the public's views; and
- Whole-of-system planning for AVs.

From a policy perspective, what is the government's role in enabling AV testing and operating environments? What are the public's expectations, and how should policy goals be formulated? How does the public react to technological innovations in transport? What is the "social license" for AV? What are the negative impacts, and the longer-term effects on public goods and common goods? For example, AVs will drive at the speed limit and yet trip times will be shorter – will this altered "balance of expectations" appeal to the public?

Infrastructure and Freight

Infrastructure preparation for AVs will eventually need to go beyond the sensor-friendliness of roadway signage and delineation. What further stages of infrastructure adaptation and re-design will be required? The deployment of CV is a critical enabler; consideration needs to be given to priority infrastructure elements for such deployments. Considerations for heavy vehicles include signal timing and priority, and movement in platoons.

There is an important infrastructure policy role for the management of security credential systems – which cannot simply be confined to vehicles – and for governance concerned with co-operative systems platforms and applications.

4.3 Emerging Digital Transport Research Clusters for Australia

The topics discussed at the Summit were driven by the cross-cutting considerations of technology, especially CAV and related data platforms. The social and economic ramifications of new transport technology emerged in three clusters, all of which have important research requirements:

- **A safer system:** technology is already being used to reduce the propensity for driver error in crash causation; how can this expanded and made available to all?
- **Active transport:** technology, in the form of a platform available to users, permits real-time integration of a spectrum of transport modes in a community; what is the willingness of the community to engage in large-scale data exchange, and how is safety to be managed in an ad hoc system?
- **The social license for AVs:** highly-automated vehicle services will not only impact safety and mobility, but will have far-reaching effects on "the commons", the environment and communities; how can major technical challenges be dealt with responsibly in an accelerated manner?

The economic and societal importance of these ideas propels us to recommend a larger collaborative Australian research effort in ***safe, active transport systems with increasing connectivity and automation***. We note that, although the Summit focused on safety, the broader significance of these research clusters must be acted upon. We envisage three major thrusts to be undertaken under joint government and industry funding. It must be recognized that these ideas all involve co-operative systems of varying levels of complexity; bold initiatives by government, industry and academia are needed to create momentum and trust.

In order to maximize the utility of government and industry resources, gain momentum with CAV testing and provide a focal point for international collaborations, we propose the establishment of a government-supported **CAV scientific council** to advance the CAV knowledge economy – including the design and progress of CAV testing – and to advise on a range of societal issues including safety, and to provide independent outreach. Key scientific and educational issues associated with the three research clusters include: artificial intelligence, smart infrastructure, functional safety, human factors, communications and networks, data science, and social research. In addition, a **CAV industry council** should be created to provide rapid response and advice on testing, deployment and economic issues.

A Safer System

Australia's over-riding transport safety philosophy is the "safe system", as adopted in many other countries. Australia is an acknowledged leader in road safety research and practice. The deployment of connected vehicle and infrastructure technology provides an unequalled opportunity for avoiding specific types of driver errors. Such deployment should encompass vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and "vehicle-to-everything" (V2X) technologies. V2X is a standardized technology platform (at national and international levels) that lends itself to the targeting of local crash issues and types. Further, it supports the stage-by-stage rollout of automated vehicles and their operating domains.

Government initiative and financial support is needed to create a critical mass of infrastructure-based V2X deployments in diverse Australian locations. AIMES and the Queensland Co-operative and Automated Vehicle Initiative (CAVI) are good examples. Industry support is needed to develop effective crash avoidance applications and equip fleets of vehicles. Academic institutions need to convene the ecosystem, curate the test deployments and develop independent data exchanges. Most importantly, institutions need to actively network, share data between V2X locations, promote the next era of safe system research, and evaluate safety advances. This should be done under explicit collaborations between Australian and overseas V2X consortia.

A Platform for Active Transport

Australia's cities are highly car-dependent and congested. Travelers themselves need to contribute to the development of platforms that know more about traveler intent and can redirect across the system in real time. The system comprises personal vehicles, shared and on-demand services, technological shuttles and mass transit. A broad spectrum of devices, sensors and communication regimes is needed. The emphasis should be on evolving and evaluating attractive platforms for connected multi-modal trips that select from private cars, new mobility services and mass transit.

Industry-government initiative is needed to create active transport platforms and communities of users in several Australian cities, and to promote smaller urban departments built on active transport. Government partnerships are needed to help develop multi-modal system elements. Academic institutions need to convene the ecosystem, working closely with government agencies and ensuring that user preferences are scientifically addressed. Clear and accessible bodies of knowledge will be needed to build successive layers of real-time systems and to guide urban infrastructure development. International collaborations will enrich our understanding of user preferences in widely differing environments.

A Social License for CAVs

If the future direction of Australia's transport policy is to entertain the wide-spread, constructive use of AVs, it is essential to deal with safety issues related to AV technical performance and operation with conventional traffic. It is unlikely that AVs will have sufficient public support without a globally-consistent Australian testing capability specific to Australian AV operations and supporting infrastructure. This would include off-roadway AV testing, curated on-roadway testing and AV services including driverless ride services.

Government leadership and financial support is needed to create the necessary off-roadway and on-roadway facilities. Industry partnership is needed to deploy AV ride services. A single off-roadway facility is suggested, along with several on-roadway curated sites in diverse locations, and able to support driverless ride services. Each site needs an operational consortium and independent convening to further develop educational and economic development imperatives. International research co-operation and exchange is needed to accelerate progress.

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Acknowledgements

The authors wish to acknowledge the valuable contributions of the summit speakers, moderators and rapporteurs, and the engagement of all participants. We take this opportunity to express our appreciation to: Amanda Caple (Victoria Chief Scientist), Miranda Blogg (Queensland Transport), Ann Brach (TRB), Marcus Burke (NTC), Anita Curnow (Vicroads), Barry Einsig (Cisco), Knut Evensen (Q-free), Emilie Van Der Graffe (Yarra Trams), Jamye Harrison (WSP), Kevin Kerrigan (MEDC), Natasha Merat (University of Leeds), Someem Moslih (Vicroads), Roland Pittar (Department of Infrastructure), Kirk Steudle (MDOT), Alison Stewart (Infrastructure Victoria), Cecilia Warren (IAG), David Young (TAC) and Simon Young (Cisco).