

INTELLIGENT VEHICLES + INFRASTRUCTURE TO ADDRESS TRANSPORTATION PROBLEMS – A STRATEGIC APPROACH

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ABSTRACT

Transportation systems around the world are showing signs of strain, and safety, congestion, and energy usage are significant societal problems. In the past, transportation professionals have attempted to solve these problems through largely "siloeed" approaches focused on vehicle crashworthiness, infrastructure design, or energy efficiency. These separate approaches have had success, however transportation problems continue to grow.

The University of Michigan has formed the Mobility Transformation Center (MTC) to create a consortium of industrial, government, and academic partners who comprise an ecosystem for enabling a future transportation system that leverages connected and automated technologies. This group has convened to define a potential ecosystem, identify and prioritize key research needs for enabling a holistic approach, identify key technology and policy hurdles with paths forward, identify business drivers and opportunities, as well as identify gaps in standards, testing, facilities, and risk management schemes. A key goal is to lay a foundation for, and demonstrate, a commercially viable connected and automated transportation system in Ann Arbor by 2021.

To achieve these goals, MTC is designing, building, and deploying significant test beds, facilities, and deployments so that real-world results can be incorporated into this process in a rapid fashion.

This paper presents a summary of current status and early results of this effort, to the extent that they are ready for dissemination. This includes a description of the role various industrial sectors may play in a future transportation system, as well as identified first-level research gaps.

Included is a high-level description of strengths and weaknesses of various technologies (vehicle sensors and communication, infrastructure sensors and communication, infrastructure operating systems, data systems, etc.) and their ability to address key transportation problems and opportunities.

Lastly, a summary of the current status of the physical test beds and deployments will be included.

The authors seek to further the discussion of the potential roles various transportation system components and industrial sectors, as well as the roles for government and academia. Additionally, the authors hope to generate meaningful discussion on the importance of a systems approach to solving key transportation problems, including proper technology planning, evaluation and deployment to ensure that results address the widest range of societal needs as possible.

INTRODUCTION

Transportation systems around the world are showing signs of strain, and safety, congestion, and energy usage are significant societal problems. In the United States 32,719 people were killed in motor vehicle crashes in 2013, and 2,313,000 were injured [1]. While these were decreased from 2012, motor vehicle crashes remain as a significant and persistent societal problem.

Similarly, traffic congestion is a well-known persistent problem in many U.S., and international cities, with significant impact on national economy and quality of life. It is estimated that congestion costs the U.S. over \$120B annually, and causes 2.9B gallons of wasted fuel [2]. Unless unchecked, there are expectations that these costs and negative effects will increase as the population rises in the next 50 years.

In the past, transportation professionals have attempted to solve these problems through largely "siloes" approaches focused either on vehicle crashworthiness, infrastructure design, or energy efficiency. These separate approaches have had success, however transportation problems continue to grow.

New technologies including communication systems, automation, and "big" transportation data systems are being developed to address various problems. For the high-level strategic purposes of this paper, the following definitions are employed:

Connected – technologies that enable direct or indirect communication to and between transportation agents including vehicles, infrastructure, pedestrians, operation centers, and other entities. These include DSRC, cellular, Wi-Fi, satellite, and other media, and enable many applications and functions including navigation, driving information, infotainment, V2V, V2I, I2I, V2P (pedestrian), mapping, amongst others.

Automated Vehicles – technologies that enable automatic operation of some or all safety-critical control functions, including steering, throttle, braking, and motive power selection (forward, reverse, and other), and at various levels of occupant involvement or monitoring. Generally, the NHTSA-defined levels of automation will be used [3].

"Big" Transportation Data – data systems and technologies that gather, amalgamate, analyze, and report on numerous significant transportation and related data streams, such as vehicle-based data, telemetric data, fleet data, location data (to the extent that privacy is appropriately protected), operations data, maps, video data, weather, crash data, fuel usage data, amongst others. These systems must also address key components of cybersecurity and privacy.

The overarching premise is that a systems approach, encompassing all three technologies listed above, must be employed to ensure that society receives the maximum benefit from these technologies. Each of these are extremely complicated technologies, especially when applied to the very large scale of a national transportation system. If any of these are developed in isolation, we will not fully address the key needs of a future transportation system: safety, mobility, and energy efficiency.

As an example of this systems approach philosophy, MTC embraces the idea that these Connected and Automated vehicle technologies will not only function well together, but will be developed simultaneously and be very complementary to maximize the functionality and benefit of each. MTC has subjectively considered the relative pros and cons of various applications of these technologies, and the results are shown in Table 1. Generally connected technology is relatively inexpensive, provides otherwise unavailable information on road partners and conditions, and provides a longer range "sensor" data compared to typical radar, camera, and lidar sensors. On the other hand, connected technology requires a

significant concentration of equipped vehicles/infrastructure, still relies ultimately on actions of human drivers, and can be perceived as a relinquishment of privacy.

Generally, automated technology can reduce dependencies on human action (and presumably error), doesn't rely on equipage of other vehicles, and has a high consumer interest. On the other hand for the highest levels of automation, the cost of sensors and onboard computing is quite high (which may limit broad adoption), the technology is not easily retrofitable and is not proven, and requires significant policy decisions and potentially changes for licensing, insurance, enforcement, etc.

	pros	cons
Connected		
V2V	proven effective for safety - avoiding collisions	relies on driver reaction
	inexpensive - can be applied on many vehicles	relies on other vehicles (critical mass)
	retrofitable	requires security system
	sees around corners	perception of privacy loss
	sees through fog/rain/snow	
	sees at longest sensor range	
	sees multiple vehicles ahead	
	knows much more about road partners	
+ V2I	enhances mobility thru adaptive signal control	requires infrastructure investment
	enhances energy-use through eco routing/timing	requires added security system
	enables weather apps	further perception of privacy loss
	enables 0/1st level eco-driving	
	enables pedestrian detection in crosswalk	
	enables smart parking	
Automated		
AV	relies less on human intervention	expensive - can't be applied on many vehicles
	doesn't rely on other vehicles	technology not fully ready
	added driver convenience	not yet proven reliability
	high customer interest	not retrofitable
	potential for improved safety, unproven	requires security system
	potential for improved eco-driving	requires policy decisions/changes
		unclear if all veh data can remain private/anonymous
		may add VMT due to convenience
Automated + Connected		
AV + V2V + V2I	all advantages above	most disadvantages above
	adds reliability to sensing & decision making	added cost
	enables platooning at close following distance	added proveout requirements
	enables safer lane changing and passing	requires comprehensive security system
	communicates locations of map changes/updates	
	communicates road construction / maintenance	
	enables 2/3/4th level eco-driving	
	enables L4 driverless (on most roads)	
all + V2P	enables safe urban operation around pedestrians	requires smart phone/device solution
	enables rapid retrofit system	

Table1.
Comparison of relative pros and cons of various applications of technologies.

MTC has also considered, albeit subjectively, the relative future potential capabilities for these technologies to deliver key benefits in the form of core transportation metrics, namely safety, mobility, environment, and convenience, shown in Table 2. Generally, both technologies provide some potential benefit in all of these categories, though primarily to lower costs and greater penetration, connected technology provides a greater portion of safety and mobility benefits. While automation, primarily due to

the ability to relieve the driver provides significant convenience, especially at the highest levels of automation. Both technologies may play an equal role in delivering environmental benefits, and future research programs should strongly consider inclusion of a focus on environmental and energy saving opportunities for these technologies.

Because of these significant benefits, and in spite of the challenges, MTC has concluded that it is very likely, perhaps necessary that both technologies continue to be developed and deployed, along with accompanying data systems. This dual development will take advantage of significant synergies between the technologies and provide significant opportunities for benefit in key transportation metrics. Ultimately the expectation is that the benefit will outweigh the investment costs in both vehicles and infrastructure.

		Safety	Mobility	Environment	Convenience
Connected					
V2V		5	2	2	1
V2I		1	5	3	2
Automated					
L2		2	1	2	1
L3		0	0	1	2
L4		2	2	2	4
Con+Auto		10	10	10	10

Table 2.
Relative benefit levels for Connected and Automated technologies.
(Higher number indicates increased benefit)

ESTABLISHING an ECO-SYSTEM

The University of Michigan has formed the Mobility Transformation Center (MTC) to create a consortium of industrial, government, and academic partners who represent a potential ecosystem for enabling a future transportation system. This group has convened to define a potential ecosystem, identify and prioritize key research needs for enabling a holistic approach, identify key technology and policy hurdles with ways forward, identify business drivers and opportunities, as well as identify gaps in standards, testing, facilities, and risk management schemes, all with the goal of fielding a significant demonstration of a working system in the next 6 years.

After surveying the current state of development of the above technologies, the following industries were identified as critical to a future transportation system:

- Auto and truck manufacturers
- Auto components and systems
- Telecommunications & communication services
- Consumer electronic devices

- Big data management and mapping
- Freight movement and logistics
- Traffic control systems
- Insurance
- Public transportation
- Payment systems
- Parking operations and systems

In parallel with industrial efforts, governmental bodies that have operational and jurisdictional roles at the national, state, city, and local levels are critical stakeholders. Lastly, academia must play a critical role in identifying, developing, and evaluating key technologies and as agents of change. Together, by including stakeholders from all of these realms, MTC has formed a true public-private partnership to further the technology, identify policy issues, and where needed, changes, spur innovation, provide living laboratories to test and evaluate technologies, and prototype an entire working system to identify at least one path forward to large-scale deployment.

KEY RESEARCH NEEDS

The MTC has undertaken an extensive effort to identify, understand, categorize, and prioritize the state of art of the three key technologies from the viewpoint of members and stakeholders. Based on this effort and the resulting state-of-art assessment, a number of research thrusts were identified in two different categories:

Technology

- Connectivity (V2X)
- Automation
- Cybersecurity
- ITS Interoperability
- Data Analytics
- Human Factors
- Energy Use & Emissions
- Standards
- Regulatory Issues
- Compliance

Policy

- Congestion Management
- Consumer Acceptance
- Public Policy
- Urban Planning
- Infrastructure Design
- Social Implications
- Legal Issues
- Business Models
- Payment Methods

Based on the above research thrusts, MTC has collected, brainstormed, and refined a number of research questions that need to be addressed to enable an accelerated and meaningful step towards significant demonstration. This full list of research questions is too long to reproduce fully in this report. And of course not all of these research topics can be addressed at one time, or in the context of pre-competitive research. Therefore MTC, along with its Leadership Circle Members, has undertaken a prioritization effort to identify the first and most critical research thrusts and research questions. These are shown below, in appropriate categories.

Connected Technologies

- What applications, beyond safety, bring day-one value to the users and stakeholders?
- How are safety benefits extended to all road users including pedestrians?
- What is the business model of connected infrastructure deployment?
- How will a full-scale Security Credential Management System (SCMS) function?

Vehicle Automation

- How can automated vehicle technology be tested and validated to determine readiness for deployment?
- What role does the built roadside infrastructure play in a connected + automated environment and specifically what upgrades or updates, if any, would be required?
- What role does the data and mapping infrastructure play in a connected + automated environment and specifically what upgrades or updates would be required?
- What is the process to achieve broad acceptance and engagement with the community?

“Big” Transportation Data

- What are the key cybersecurity risks and needs for automated vehicles?
- What data sets are required for connected + automated vehicles and what will be the tools and analytical approach?
- What data should be collected, and how are they useful for different purposes?
- How can the data drive entrepreneurship and new business models?
- How can the data support product development?

Policy

- What any changes if any are required to our legal system to maximize the value to connected + automated? State vs. Federal, Shared liability regimes, etc.
- How will fault be assessed in Automated Vehicle (AV) crashes?
- What are the key privacy impacts of automated vehicles?
- Do we need an ethics decision-making model for vehicle automation?

Customer Acceptance

- How do you define and measure value & customer acceptance?
- How do you define and measure value for all stakeholders (municipalities, etc)?

Standards

- What are the gaps in standards gaps for CAVs? which are a priority?
- Are existing regulations impediments to testing of connected and automated vehicles?
- What is the role of simulation in the prove-out of automated vehicle standards?
- Is a new testing methodology required to test the safety of connected and automated vehicles (confirmation of good events)?

Societal Impacts

- What is the implication of AVs on traffic congestion and VMT?
- How does a fully evolved connected and automated environment impact congestion, mobility, energy, public health, etc?
- What is the behavioral and economic impact of automated transportation?
- How will AVs impact urban transportation and design?
- What are implications for AVs on the aging population?

MTC has begun conducting internally-funded research projects on some of these, and other, questions and topics. The first round of research results and tools will be available in the August 2015 timeframe, and the second round was kicked off in April 2015. Results will be discussed at MTC Annual Congress, currently being scheduled for September 2015 in Michigan.

DEVELOPMENT and DEMONSTRATION PLANS

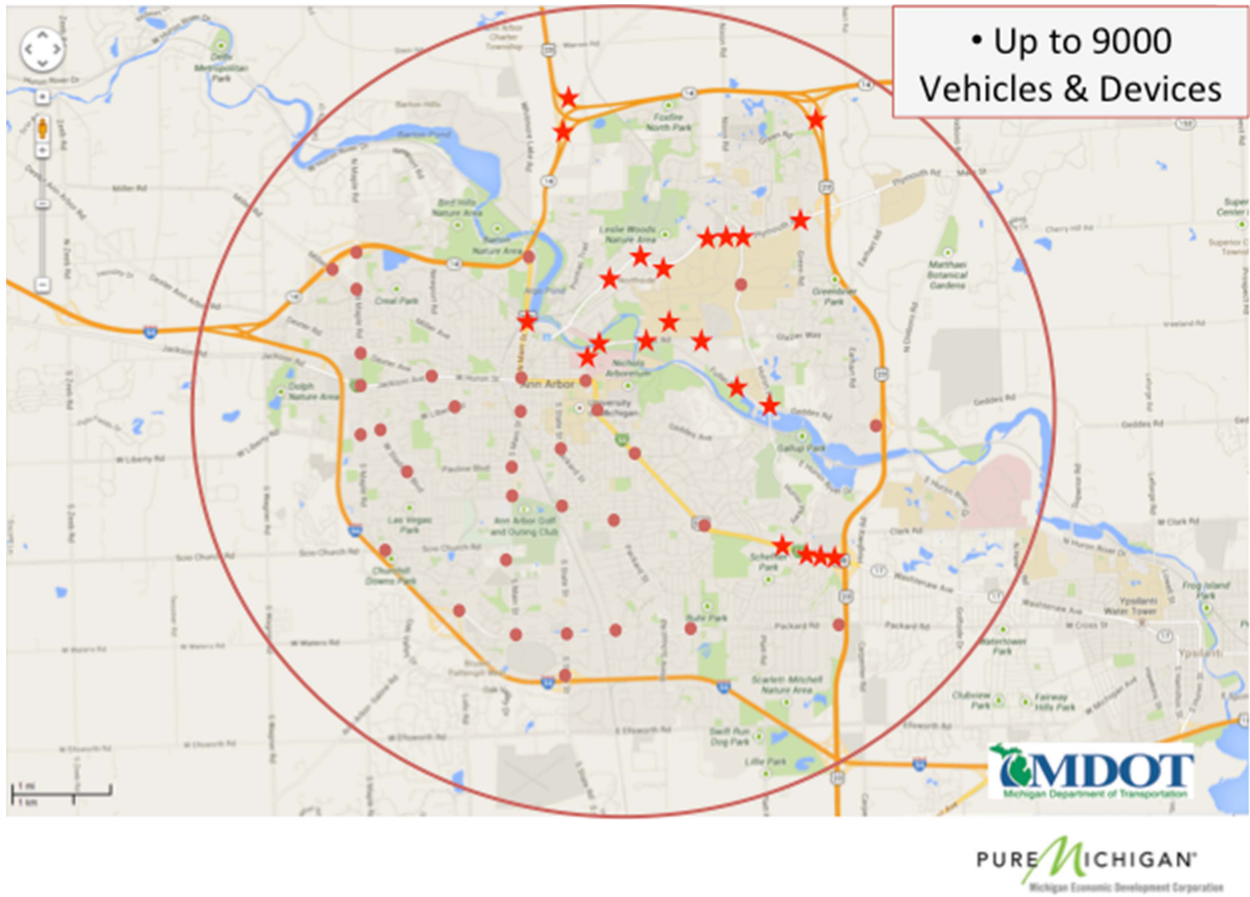
MTC believes that there are a number of significant, complex, and often intertwined questions and unknowns that need to be addressed to develop and deploy these technologies. These questions include those listed above, as well as many others. If left to standard, and individual, product research and development processes, these questions would likely require a decades-long product rollout. But given the significant potential benefits for transportation, MTC believes that these processes should be accelerated. MTC is promoting acceleration through collaborative efforts, and by fielding meaningful and ambitious model deployments to provide “living laboratories” and by creating unique purpose-built test facilities. MTC has undertaken work to build three “pillar” model deployments and one test facility.

Pillar 1: Connected Ann Arbor

MTC, with the collaboration of the City of Ann Arbor, will build on the success of the USDOT-funded Connected Vehicle Safety Pilot Model Deployment and expand that deployment up to 9,000 connected vehicles, and over 65 infrastructure nodes. This deployment will shift focus towards V2I applications, specifically those that can provide “day-one” benefits to drivers, road operators, cities, and importantly, vulnerable road users including motorcyclists, pedestrians and bicyclists. Figure 1 shows the geographic layout of this concept.

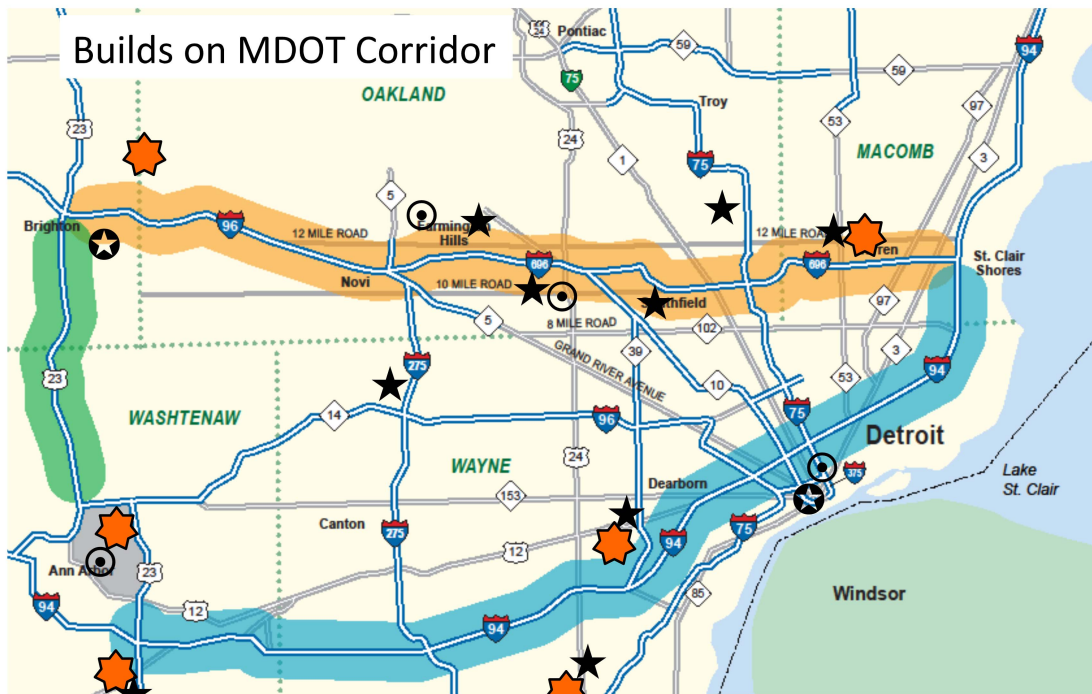
Pillar 2: Connected Southeast Michigan Initial Deployment

MTC, in a partnership with Michigan Department of Transportation (MDOT), member companies, and others, taking advantage of the region’s uniquely large number of V2X activities and stakeholders, will create the first large scale connected transportation deployment in the United States. This deployment will leverage the MDOT Connected Corridor Program, as well as encompass the four existing test beds in the region, including Ann Arbor, Novi/Farmington, Telegraph Road, and City of Detroit. This deployment will focus also on V2I applications, especially to quantify benefit for road operators and municipalities for future investment decisions. Additionally, this deployment will support the auto industry by providing a dense connected environment to finalize development of V2V technology ahead of a NHTSA mandate. This deployment will also provide a unique opportunity to prototype and test a fully functional SCMS that can be scaled nationally. Lastly, this deployment will support early research and product development of AVs. Figure 2 shows the geographic layout of this concept.



- 60 Intersections
- 3 Curve-related sites
- 12 Freeway sites
- Over-the-air security
- All DSRC communications logged
- Backhaul communication network
- Back-end data

Figure 1.
Pillar 1: Connected Ann Arbor, MI



- ★ MDOT Facilities
- ★ LC Member HQ or Key Facility
- Connected Vehicle Test Beds
- ★ Automated Vehicle R&D



Figure 2.
Pillar 2: Connected Southeast Michigan Initial Deployment

Pillar 3: Automated Ann Arbor

MTC, in collaboration with the Leadership Circle of Companies, MDOT, and with the City of Ann Arbor, will utilize the dense connected Ann Arbor deployment to deploy an on-demand transportation service including 2,000 automated vehicles (AVs), including some number of levels 2, 3, and 4 vehicles. This transportation service will include the movement of people and goods, and will serve as a prototype for a future transportation system that will provide significant transportation benefits to the city and community. This deployment will include a fully-developed simulation platform (sensor, vehicle, driver, communications, infrastructure, environment) to complement the on-road environment. This deployment will leverage a to-be-developed “smart city” data and digital infrastructure, including backhaul and functions. It is expected that this deployment will also provide

an incredibly rich environment for product research and development, as well as addressing both technical and policy issues and questions.

Purpose-Built Test Facility: M City

MTC believes that a combination of both test track and on-road testing will be required for full development of high level AVs. Test tracks can provide a safe, controlled, and repeatable environment for early development without putting an unknowing public, especially pedestrians, at risk. And on-road testing is required because no track or simulation can anticipate the full plethora of conditions and scenarios that human drivers negotiate in the real world.

Therefore, MTC has designed and constructed a new, one-of-a-kind purpose built test facility for connected + and automated vehicles, named M City. This facility is designed to be a condensed, built to standard, simulation of a US city that will appear as a real environment to AV sensors. It is located directly adjacent to the Pillar 1 Connected Ann Arbor environment. Figure 3 shows the concept model of M City.



Figure 3. Conceptual model of M City.

M City includes an urban area with 13 intersection of various geometric designs, various road surfaces, curves of varying radii and elevation, round-about, traffic circle, building facades of varying geometry and materials, various traffic control devices and signage, pedestrian crossings and

bike lanes, street lighting, and mechanized pedestrians and bicyclists, amongst other features. It also includes a simulated highway stretch with on and off-ramps, multiple surface materials and markings, overhead and post-mounted signage, etc. Additionally, like the Automated Ann Arbor deployment, a full complement of simulations and tools will accompany the physical test facility.

Civil works and construction for this facility were completed in November 2014, with equipage of traffic control devices, lighting, and building facades scheduled at the time of this writing. The facility is expected to be fully operational by July 2015. Figure 4 shows an aerial photograph and layout of M City.



Figure 4. Aerial photograph of M City.

MTC and its private and public partners intend to utilize these deployments and this facility, and any others like it around the world, to conduct research and aid development of harmonized testing regimes, criteria, standards, and even future regulations that can speed the deployment of AV technology. MTC welcomes collaborations with other research and development stakeholders to achieve this goal.

CONCLUSIONS

MTC has been formed to accelerate the development and deployment of connected and automated vehicle technologies, and believes both will be needed, and are largely complementary, to achieve significant improvements in our future transportation system. Many significant technical and policy questions remain to be answered, and model deployments will be a powerful, and likely necessary, tool to address these questions and find a way forward.

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