# Mcity Driverless Shuttle

A Case Study


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UNIVERSITY OF MICHIGAN

# Executive Summary
## Message from the Director

**Huei Peng, Mcity Director, U-M Roger L. McCarthy Professor of Mechanical Engineering**

### MCITY OVERVIEW

In June 2018, Mcity, a public-private partnership at the University of Michigan (U-M), launched the first driverless shuttle project in the United States to focus on user behavior research and extensive data collection. With two shuttles transporting students, faculty, and staff on the U-M campus, the project is designed to support data collection to understand vehicle performance, roadway interactions, and passenger attitudes. The ultimate goal is long-term deployment of driverless shuttles in the real world.

A number of recent studies by groups including AAA and the Pew Research Center have found that as many as half or more of U.S. consumers are concerned about the safety of driverless vehicles. This is not surprising.

Many new technologies are not trusted in their earliest stages of development. By testing and using these shuttles, U-M researchers have gained confidence in their reliability and safety. By providing opportunities for U-M students, staff, and faculty to experience driverless transport, we are striving to answer key questions about users' acceptance, trust, and perception of safety.

With the Mcity Driverless Shuttle project we are exploring intriguing new research territory and refining our systems in response to real-time challenges, with incomplete information and few prior examples to learn from. The main purpose of this case study is to document our experience and share what we have learned with others considering driverless shuttle deployments.

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## RELATIONSHIP WITH NAVYA

The shuttles deployed in this project were built by NAVYA, a mobility technology company headquartered in Lyon, France. We received our first NAVYA shuttle in December 2016 when the company joined Mcity as an affiliate member. We have operated this shuttle at the Mcity Test Facility since 2017. During 500 hours of testing before launching the Mcity Driverless Shuttle research project, we closely collaborated with NAVYA on system requirements and improvements specific to our research environment, including safety belts and a bespoke data acquisition system. Two additional shuttles were purchased in late 2017, with financial support from Mcity's corporate members. Shuttle research operations are financially supported by U-M funds.


**NAVYA Founder and CEO Christophe Sapet speaks during an event at Mcity in December 2016 that marked the debut of NAVYA's driverless shuttle in North America.**


**The first Mcity Driverless Shuttle operated inside the Mcity Test Facility for more than a year before testing began on U-M campus roads.**

# 01 Project Description

Mcity is studying how passengers and other road users interact with the driverless shuttles to gauge consumer acceptance of the technology.

## Project Description

**The primary goal of this research project is to understand human acceptance, trust, and behavior when riding in a driverless shuttle or interacting with one on the road.**

We are collecting both subjective survey data and objective data from interior and exterior sensors, including machine vision cameras, microphones, precision GPS, and vehicle dynamics. The outward-facing cameras help us to capture and identify the interaction between these shuttles and other road users, including pedestrians, cyclists, and vehicles. The interior cameras capture information about ridership and serve as a security system. Interior microphones can also help us to understand rider sentiment and emotion. Precision GPS and vehicle dynamics sensors help us to understand how shuttle movements relate to the behavior of passengers and other road users as captured by the on-board cameras and microphones.

Data is gathered as the shuttles operate on campus, offering the U-M community a real shuttle experience. Ridership information helps U-M understand mobility needs near the North Campus Research Complex (NCRC) and informs planning for future bus and parking needs.

The Mcity shuttles currently operate at a maximum speed of 12 miles per hour. They scan the environment continuously and stop completely at every stop sign. Because this behavior is more cautious than most vehicles driven by humans, we anticipate that the shuttles will create interesting interactions with other vehicles, pedestrians, and cyclists. These interactions are well documented by our external camera systems. We expect to capture hundreds of cases that will help us gain insight into traffic behaviors. This learning will help us contribute to the design of better future driverless vehicles and possibly help us define a "code of conduct" to promote safer operations.

Driverless shuttles have a future only if they are trusted and used by riders, and trusted and accepted by other road users. For the Mcity Driverless Shuttle project, safety was the most important factor in route selection, setting operational speed, and programming behaviors at intersections. We also developed a rigorous training and operating procedure for the onboard safety conductors, who play several important roles.

## Safety conductors provide an extra layer of assurance for safe operation.

Safety conductors provide an extra layer of assurance for safe shuttle operation. Their presence reassures riders who are new to the driverless environment. They ensure that all riders are properly seated and wearing seatbelts. They encourage all riders to participate in data collection by completing the user survey. The value of the safety conductors cannot be over-emphasized.

The user survey was designed in close coordination with JD Power, a global market-research firm with deep expertise in consumer attitudes toward automotive products and an affiliate member of Mcity. The survey questions focus on understanding the attitudes of riders and non-riders toward driverless shuttles. The survey includes longitudinal tracking to help us understand how user attitudes change over time.

Both objective and subjective research data will be shared with Mcity's Leadership Circle and Affiliate members, and U-M researchers. Results will be shared more widely through Mcity white papers and other publications.

**An on-board safety conductor oversees shuttle operation at all times. The conductors wear an Mcity cap and t-shirt to help riders identify them.**

**The interface on the driverless shuttles is designed for effective communication to display key vehicle information and receive human input.**

FIELD NOTE

The Mcity Driverless Shuttle project was designed to achieve the specific research goal of understanding passenger and road user behavior while ensuring a safe deployment. Research needs and safety shaped the route environment, data acquisition, and operational plan.

# 02 Stakeholder Engagement

Successful deployment of the Mcity Driverless Shuttle research project required extensive collaboration with a diverse group of internal and external stakeholders.

# Stakeholder Engagement

Close coordination within U-M and with partner organizations outside the university was critical in taking the Mcity Driverless Shuttle project from idea to reality.

## INTERNAL STAKEHOLDERS

**University of Michigan Office of Research (UMOR)**

In addition to its role in fostering new research, UMOR provides oversight for research policies, compliance, and ethics. UMOR's engagement and leadership provided overall institutional support to launch Mcity's driverless shuttle research and to ensure compliance with all of U-M's rules and regulations related to projects that include human subjects.

**Office of the Vice President and General Counsel (OGC)**

OGC supported Mcity by evaluating the regulatory landscape for deployment of driverless shuttles on publicly operated, university-owned roadways through engagement with the U.S. Department of Transportation and the Michigan Department of Transportation. OGC also managed the terms of procurement for the shuttle vehicles and explained the project's legal risks and challenges to the research team and university executives.

**Institutional Autonomous Systems Committee and Institutional Review Board (IASC and IRB)**

The IASC and the IRB ensure U-M research is safely and ethically conducted. Early and frequent engagement with both organizations provided Mcity with valuable expertise in determining safety considerations as well as oversight in the management of human subjects. Due to the nascent nature of the technology, an iterative process in reviewing our safety, testing, operational plans, and privacy protocols was an important approach.

**Logistics, Transportation & Parking (LTP)**

LTP operates the U-M bus system, making it a natural partner in the shuttle research project. At the onset of the project, all parties agreed to have the campus transportation experts handle the day-to-day operations of the shuttles, allowing Mcity to focus on the research elements.

Early engagement with LTP was critical in understanding traffic patterns on campus and assessing the appropriate operating area for the shuttle from a campus perspective. Low-speed shuttle deployments are often developed for campus or private sites, where engaging the local transportation provider is an important step in integrating these mobility solutions into a larger context. In an early stage of our project, we worked with LTP bus drivers and shared with them expected shuttle behaviors. For example, large and heavy buses should not follow too closely behind the shuttles, which can stop quickly. This consideration was emphasized in training videos produced for the LTP bus drivers.

### Department of Public Safety & Security (DPSS)

Law enforcement officials must be included in the early stages of a shuttle deployment project so they have a complete understanding of the system's capabilities and the challenges that may arise in real-world operation. DPSS was involved in the Mcity project in two important ways:

- The local DPSS team responsible for the shuttle operating area was invited to a shuttle orientation and then provided security during the low-speed mapping required to define the initial route. This provided an added measure of safety as the shuttle traveled below posted speeds during data collection.

- Mcity worked with DPSS to review incident protocol so they could update their reporting procedures based on mock crash scenarios for an automated vehicle.

### Environmental Health & Safety (EHS)

Like any other mode of transport, potentially hazardous situations may arise following an incident involving the Mcity shuttles, which are electric as well as driverless. Special attention must be devoted to the battery system if the vehicle structure is compromised. Damage to the batteries could cause fires or hazardous material leaks. Mcity provided EHS with an overview of the shuttle and its operation, along with documentation of battery lockout procedures initiated by the shuttle conductors or other first responders to disconnect the batteries from the shuttle if there is a crash. Providing general awareness and training for EHS establishes optimum preparedness during real-world operation.

### North Campus Research Complex (NCRC) Community

Efficient, effective interaction with the targeted rider community and other road users is critical for user adoption and safety. In the weeks and months leading up to deployment, Mcity worked with the NCRC communications staff to deliver information about the shuttle in NCRC's weekly newsletter to all employees. This group included potential shuttle passengers and daily road users who shared the shuttle's route.

In addition, a list of frequently asked questions was shared with the NCRC community, such as "Will the shuttle stop for me if I am at a crosswalk?" and "Where are the shuttle stops?" Shuttle information was shared more broadly via the Mcity Driverless Shuttle landing page added to Mcity's website, mcity.umich.edu/shuttle.

## EXTERNAL STAKEHOLDERS

**Ann Arbor Public Schools & First Responders**

The shuttle route is located on the U-M campus, but includes public roads traveled by many other vehicles. Mcity briefed the Ann Arbor Police Department and the Ann Arbor Public Schools on shuttle operations that may interact with school-bus routes and explained the safety instruction provided to university bus drivers who frequently encounter the shuttles.

**National Highway Traffic Safety Administration (NHTSA)**

NHTSA was an early stakeholder, not only in providing some procedural exemptions for the shuttle operation, but also as a partner in refining our incident response plan. Working with NHTSA, we ensured a smooth process for timely transfer of information in the event of a crash.

**Efficient, effective interaction with the targeted rider community and other road users is critical for user adoption and safety.**


**Communication with potential shuttle passengers was an important element for a smooth launch.**

### FIELD NOTE

Identify key stakeholders early in the process of considering a shuttle deployment, and engage them often through planning and after launch. Their insights are invaluable and can flag potential obstacles before they slow down progress.

# 03 Licensing, Insurance, and Approvals

In all automated vehicle projects, it is critically important to recognize and resolve a broad range of legal, regulatory, and liability issues.

# Licensing, Insurance, and Approvals

In December 2016, Michigan Gov. Rick Snyder signed into law automated vehicle legislation that permits operation of driverlesss vehicles on Michigan roads.

**Michigan Gov. Rick Snyder signing automated vehicle legislation that, among other provisions, cleared the way for university researchers to operate automated vehicles on public roads.** PHOTO CREDIT: RYAN BURLOW, MICHIGAN RADIO.

## STATE OF MICHIGAN

### AUTOMATED VEHICLE LEGISLATION

In December 2016, Michigan's Gov. Rick Snyder signed into law automated vehicle legislation that permits the operation of automated vehicles on Michigan roads. Prior to this legislation, the State of Michigan permitted the testing of automated vehicles by manufacturers on public roads. The new law took the form of an amendment to the Michigan Vehicle Code.

The Michigan Vehicle Code now permits the operation of automated vehicles on public roads, and explicitly permits university researchers to operate driverless vehicles, provided they comply with the applicable Michigan Vehicle Code requirements. Additionally, the Michigan Vehicle Code requires that the person "operating the vehicle" be able to take control of the vehicle's movements in case of an emergency. Alternatively, if the person "operating the vehicle" cannot take control, then the vehicle must "be capable of achieving a minimal risk condition."

With the passage of the amendment, the operator is no longer required to be inside the vehicle. The State of Michigan was among the first states to remove such a requirement, which will pave the way for the deployment of fully automated vehicles. As safety is of the utmost importance to U-M, Mcity requires that an operator (a safety conductor) be present on its automated vehicles at all times with the ability to take control of the vehicle if necessary. Moreover, as required by the Michigan Vehicle Code, each safety conductor is licensed to operate a motor vehicle in the State of Michigan.

While legislation regarding the operation of motor vehicles is traditionally under the purview of the states, regulation regarding the design, manufacture, and safety of motor vehicles is within the federal government's scope of authority. Prior to the recent adoption of automated vehicle legislation by certain states, virtually all U.S. laws governing the design and operation of motor vehicles were written for motor vehicles operated by a human driver. More importantly, Federal Motor Vehicle Safety Standards (FMVSS), which are the federal regulations that establish minimum safety performance requirements for motor vehicles and items of motor vehicle equipment, do not directly address the myriad issues related to automated vehicles.

**The State of Michigan is the first state to pass comprehensive self-driving regulations.**

By way of example, FMVSS 101 (vehicle controls and displays), 108 (lamps, reflective devices, and associated equipment), 111 (rear visibility), and 135 (braking systems) each address the interaction between a human operator and (1) the vehicle under the operator's control or (2) the other vehicles sharing the road. Prior to the enactment of automated vehicle legislation by Congress, manufacturers or operators of automated vehicles that do not comply with FMVSS will need to seek applicable federal exemptions.

### Insurance

The State of Michigan (in addition to other U.S. jurisdictions) has established rules, regulations, and guidelines for compulsory insurance coverage. Generally, two auto liability regimes exist, either: (1) an injured party may seek redress for torts through the court system; or (2) insurers are required to make the injured party whole without a need to determine fault. Michigan, with its no-fault insurance laws, falls into the latter category. A shift in the insurance landscape is, however, on the horizon. A combination of product liability (weighing the cost-benefit of claims cost mitigation for manufacturers) in addition to auto insurance may be the more appropriate legal and insurance framework. Before wide-scale deployment of automated vehicles, automated vehicle operators or owners may have difficulty procuring insurance coverage in the over-the-counter insurance market. Operators or owners with ample means may consider self-insuring.

FOR MORE INFORMATION

**Michigan Vehicle Code –**
**Automated Vehicle Legislation**
http://myumi.ch/JNK08


**New automated vehicle legislation signed into law by Michigan Gov. Rick Snyder in December 2016 made it possible to operate fully automated vehicles, like Mcity's shuttles, on public roads in Michigan.**

## FEDERAL

### NHTSA Exemption

The National Highway Traffic Safety Administration (NHTSA) provided updated guidance regarding automated vehicles in 2017, titled "Automated Driving Systems (ADS): A Vision for Safety 2.0." This guidance suggests that currently limited options exist for automated vehicle manufacturer exemptions. Conversely, this guidance indicates that NHTSA will encourage, as appropriate, safety exemptions for automated vehicle testing because "[t]he Federal Government wants to ensure it does not impede progress with unnecessary or unintended barriers to innovation." However, seeking and obtaining an applicable exemption is not an insignificant undertaking.

Federal regulation provides that manufacturers may apply for a temporary exemption from "any Federal motor vehicle safety … standard." NHTSA guidance specifies certain conditions for manufacturer exemptions, including substantial financial hardship, development or field evaluation of a new motor vehicle safety feature, development or field evaluation of a low-emission vehicle, or an overall safety level of the exempted vehicle that is at least equal to the overall safety level of nonexempt vehicles. A general exemption for inconsequential defect or noncompliance is also available.

Because the Mcity automated shuttles were not originally manufactured to comply with U.S. or Canadian safety standards, and are heavier than vehicles covered by applicable regulations for low speed operation, they have not been certified to meet all applicable FMVSS. For example, the following items are not present in the driverless shuttles: airbags, traditional brake or accelerator pedals, and the standard "driver control interface" (i.e. a steering wheel), among others. Understanding that non-compliance with FMVSS does not necessarily mean a lack of safety, NHTSA's Office of Vehicle Safety Compliance granted an exemption for use of these automated shuttles on public roads. In conjunction with the university's Office of the General Counsel, Mcity sought and was granted this exemption prior to importation of the shuttles. The exemption is not for the manufacturer, but for the user (Mcity in this instance). The exemption letter specified three main elements: (1) a general description of the organization requesting the exemption, (2) a summary of the research project for which the exempted vehicle would be used, and (3) the type and nature of the vehicle. When seeking an exemption, providing NHTSA with a robust analysis from the manufacturer that sets forth the 12 guiding principles outlined in "Automated Driving Systems (ADS): A Vision for Safety 2.0" may aid in the application process.

FOR MORE INFORMATION

**Automated Driving Systems (ADS): A Vision for Safety 2.0**
http://myumi.ch/J9Kkx

**Federal Motor Vehicle Safety Standards**
http://myumi.ch/6vyeR

## LOCAL

### Institutional Autonomous Systems Committee (IASC)

U-M established the faculty-led Institutional Autonomous Systems Committee (IASC) to provide a review and approval mechanism for drones and autonomous ground vehicles operated by anyone on U-M property. Review of our research plan by the IASC added an additional layer of oversight and ensured better coordination among many units within the university, including the Office of the General Counsel; Logistics, Transportation & Parking services; Public Safety and Security; Risk Management, and other stakeholders. This additional oversight was very important in establishing a thoughtful and comprehensive system of driverless shuttles.

Since the selected shuttle route is completely on U-M property, Mcity was fortunate to have significant freedom in selecting the route, designating the stops, installing signs and posts, installing WiFi access points, and improving the operating environment in general.

Before the shuttles were approved for operation on the route, we conducted tests inside the Mcity Test Facility and reported our findings to the IASC. In the second phase of evaluation, Mcity staff tested operation on the route for several weeks. The safety conductors were then allowed to gain experience on the route during the third phase. Finally, the shuttles were allowed to transport riders from the U-M community. The phased approach helped to identify and resolve vehicle and operator issues gradually, which contributed to a smooth public launch.

**Mcity driverless shuttles are deployed on publicly operated U-M roadways, enabled by an exemption from NHTSA and new Michigan automated vehicle laws.**

### Institutional Review Boards (IRB)

At U-M, any research that involves human subjects is overseen by an Institutional Review Board (IRB). For the shuttle project, the IRB focused on protecting the privacy of riders, ensuring key compliance with best practices such as informed consent, control of data storage and access, etc. Due to the complexity of securing consent from both parents, minors are not allowed to use the shuttles. In addition, considering the potential exposure to uncertain risk, the project is limited to riders who are U-M students, staff, faculty, and their guests. Ridership may be expanded in the future.

**Review of our research plan by the IASC added an additional layer of oversight and ensured better coordination among many units within the university.**

FIELD NOTE

To the extent feasible, seek to engage federal, state, and local government authorities and stakeholders as early as possible, even as early as the planning stages. View government regulators as collaborators as their advice is often invaluable. Engage institutional and community stakeholders at the outset as preliminary planning and development may require significant lead times for the various stakeholders, such as insurance and risk managers, legal counsel, transportation authorities, and others.

# 04 Operational Environment

Real-world route selection required careful balance between usefulness and robust research data collection.

# Operational Environment

To select an appropriate route for the research project, we balanced the capabilities and safety of commercially available automated shuttles with sufficient interactions to produce valuable and relevant data.


**In identifying an appropriate route for the Mcity shuttles, we took into account variables such as speed, weather, and traffic patterns.**

## SPEED

Because safety is our top priority, the maximum operating speed of the driverless shuttles was initially limited to between 10 and 15 mph. So it was important to select an operating environment in which other vehicle speeds would not exceed 25 mph, and the road segments were short enough that the shuttles would not cause traffic congestion.

## ENVIRONMENT

The selected route should not include any section with a grade of more than 10 percent. In Ann Arbor, this is generally not an issue.

To mimic the quality of a useful transportation option and provide the best data collection results, we wanted to limit the average wait time to five minutes. Project budget constraints dictated that we could only operate two shuttles simultaneously, which limited the length of the service loop to about one mile. Further route expansion to other parts of campus will be evaluated as we gain experience in this first phase of research.

Route design was also influenced by selection of shuttle stops. An ideal stop is located near the deployment route, and does not require cutting through a major road with heavy traffic or high-speed vehicles. It should also be near other modes of transit, or near destinations (offices, labs, shops).

## WEATHER

The shuttles' sensor technology allows operation in a wide variety of weather conditions. However, we wanted to ensure shuttle conductors had good visualization of road conditions at all times. So the shuttle will not operate during snow or heavy rain.

Most shuttles on the market use a battery-electric propulsion system. Depending on climate, heating and cooling the cabin can consume a significant portion of battery charge, limiting operating times. Ann Arbor summer days are often over 30°C (86°F) with humidity levels above 50 percent. Winter days are often below -10°C (14°F). Heating and cooling of the shuttle cabin can require 30 – 50 percent or more of the vehicle's energy requirements during operation.

## TRAFFIC PATTERNS

**Pedestrians, Bicycles, Vehicles**

We selected routes that would have large numbers of other road users, so we could measure interactions between them and the shuttles. Time of day was a major factor in this selection. Morning and evening commute times generate 300 – 400 percent more road users than midday.



**These are the signs in use today on the Mcity Driverless Shuttle route. High-definition versions of the graphics are available for download on our website, mcity.umich.edu/shuttle.**

## SIGNAGE

Currently, there are no defined federal, state, or local regulations for signage along a driverless vehicle route. We felt it was critical to make sure all other road users in the area understood they would be interacting with the Mcity shuttles. We adapted an existing shuttle icon design for our signs. User research revealed that "Driverless Vehicle" would be the simplest phrase for other (human) road users to understand.

**An ideal stop is located near the deployment route, and does not require cutting through a major road with heavy traffic or high-speed vehicles.**

## MAPPING

Before they are deployed in the real world, the shuttles require advanced mapping of the intended operating environment, which requires driving a mapping system through the area at low speeds. This was done in the evenings or at night to minimize traffic disruption. We also coordinated with local law enforcement to provide escort during initial mapping. Initial mapping must be updated if there are changes in the infrastructure for construction along the route or in the roadway.

## SAFETY CONDUCTOR

Once a reasonable operating environment has been defined, the driverless shuttle will encounter challenges that it cannot navigate automatically. In this case, the conductor will manually navigate the shuttle to safety.

### FIELD NOTE

There are many constraints in developing an Operating Design Domain (ODD) for low-speed shuttles. Careful consideration must be given to a variety of parameters prior to launch. During operation it is important to remember you must constantly monitor these dynamic parameters, including weather, roadway and traffic conditions, and construction. Any changes could conflict with the defined ODD.

# 05 Testing

Before real-world deployment, the vehicle's system and technology were thoroughly evaluated in Mcity's world-class test facility.

# Testing

The behavior of the driverless shuttles is governed by the hardware and software designed and assembled by NAVYA. Mcity evaluated the shuttle behavior in the context of our operational environment.


**Mcity evaluated the performance of a NAVYA driverless shuttle for over a year in a variety of weather and lighting conditions inside the Mcity Test Facility.**

Safe operation of the shuttles is Mcity's highest priority for this project. For example, before launching operation on the public shuttle route, we conducted extensive testing inside the Mcity Test Facility. This was a key element of our due diligence, and provided independent insight into the operational design domain, or ODD, of the shuttles, which helped us finalize the route. The ODD defines the specific location and conditions under which the shuttle operates.

Some of the ODD parameters were provided by NAVYA (for example, maximum and minimum operating temperatures, maximum road grade, maximum payload, etc.). Others are much more complex to define and describe, and we focused on those parameters in our independent testing in the enclosed environment of the Mcity Test Facility, which allows us to test critical conditions repeatedly and safely.

In choosing the testing scenarios, we first analyzed the planned shuttle route to understand the roadway environment, intersections, and critical scenarios:

**Roadway Environment**

- Mostly two-way traffic
- Single lane each direction
- Shuttles must also navigate a parking lot with vehicles parked on both sides
- Bus bay
- Variety of road surfaces in a range of environmental conditions

**Intersections**

- All-way stops (protected)
- Two-way stops (protected)
- One-way stops (unprotected left turn or unprotected right turn)
- Pedestrian crosswalks
- Entrance to a parking structure

**Critical Scenarios**

- Pedestrians at crosswalks, at intersections, and walking along the road
- Cyclists riding along the road
- Vehicles at intersections in various conditions

Then we assembled a series of "challenges" inside the Mcity Test Facility.

**In choosing the testing scenarios, we first analyzed the planned shuttle route to understand the roadway environment, intersections, and critical scenarios.**

We created a continuous counter-clockwise loop, where the shuttle was challenged by: a cyclist moving in the same direction; a car crossing from the right; a car crossing from a slight right (at a roundabout); a pedestrian approaching from the right; a car driving in the opposite direction (close proximity); and a pedestrian approaching from the left. Then we designed and executed a similar clockwise loop. Both routes were tested many times, including in evening light conditions. Because the shuttles primarily rely on real-time kinematic positioning and LiDAR technologies for navigation, obstacle detection, and perception, we did not notice a significant difference in vehicle performance in the evenings.

FIELD NOTE

Having a separate evaluation either by your organization or a third party is an important step in evaluating a driverless shuttle for your operational design domain.

# 06 Conductor Training

On-board safety conductors monitor vehicle operation, interact with passengers, and intervene to minimize unsafe situations.

# Conductor Training

Shuttle conductors are responsible for overseeing the operation and safety of the shuttle during active use. Robust training is necessary to prepare them to take on this role.


**Mcity Driverless Shuttle safety conductors oversee the operation and safety of the shuttles while on the road.**

Safety conductors are hired by U-M's Logistics, Transportation & Parking department, known as LTP. LTP operates the university's transit systems, and is ideally suited to be the organizational lead of the shuttle conductors. Mcity partners with LTP to provide training and support specific to the driverless shuttle technology and research goals.

Safety conductors complete a robust training program before they begin their work on the driverless shuttles.

### Conductor training includes:

**An orientation session hosted by LTP and Mcity** that summarizes the technology, explains the research mission of the project, demonstrates shuttle operation inside Mcity's test facilities, explains general operating procedures, and emphasizes how to manage emergency and breakdown scenarios.

**Training Skills Set 1 – Manual Use** (three or more two-hour individualized sessions inside Mcity) teaches conductors how to operate the shuttle in manual mode:

- Getting around obstacles
- Positioning vehicle on route
- Safely stopping the shuttle
- Parallel parking
- Turning the shuttle


**Safety conductors manually control the shuttle when necessary using a hand-held unit.**

## Safety Conductors complete a robust training program before they begin their work on the driverless shuttles.

**Training Skills Set 2 – Driverless Use** (four or more two-hour training sessions inside Mcity) teaches conductors how to operate the shuttle in automated mode:

- Startup and shutdown procedures for the shuttle
- Charging the shuttle
- Getting on the path and starting the shuttle route
- Detailed process to resolve any system errors
- When and how to use the emergency stop button
- Safety for pedestrians and other vulnerable road users

### Training Checkpoint

The next step in the training process is the Examination Session. Under the direction of an Mcity trainer and an expert from NAVYA, trainees demonstrate all learned skills. If both the Mcity trainer and the NAVYA expert are in agreement that the trainee is proficient in all skills, the trainee moves on to the final session, Training Skills Set 3.

**Training Skills Set 3 – On-the-Route Training** (two weeks of on-route training provided by LTP and Mcity), allows conductors to gain comfort and practice in actual operating conditions. Items covered in this training session include:

- Access to the shuttle garage
- Signing in and out of shifts
- Obtaining keys for the vehicle
- Vehicle startup checklist
- Positioning the shuttle on the route
- Running a daily test route prior to allowing passengers
- Passenger safety procedures
- Ridership rules
- Passenger interaction guidelines
- How and when to use the radio
- Common issues
- When to use manual mode
- Emergency procedures
- Returning the vehicle into the bay
- Shutdown and charging procedures
- Post-shift documentation

**To ensure safety, conductors are provided the following:**

- An LTP radio, similar to what is used in U-M buses, so that conductors will be able to communicate with LTP dispatch in the case of a vehicle breakdown or other emergency
- Checklist to ensure proper vehicle operation
- Specific emergency procedures

**Ongoing Training**

As standard operating procedures evolve, conductors need to be aware of them. Ongoing training includes:

- Monthly meetings for presentation and discussion of operational updates, with designated time for conductors to share best practices with each other.
- Manual training on the closed test track. At least quarterly, conductors are required to practice operating the shuttle in manual mode. It is important that conductors maintain their expert skill level in maneuvering the vehicle.
- Information sharing among conductors between meetings. To share information that needs to be conveyed quickly, conductors have an online Conductor Input Form to share shift observations, issues, best practices, errors, or other information. Conductors receive a weekly conductor email that includes reminders, information from other conductors, and upcoming events.

FIELD NOTE

We found it important to have a careful progression of training. Beginning in a closed testing site – the Mcity Test Facility – allowed conductors to build confidence safely, only moving into real traffic conditions once they had demonstrated their proficiency.

# 07 Operations

Procedures, issues, and constraints associated with real-world deployment of the driverless shuttles.

# Operations

Putting driverless shuttles on the road requires a detailed operations plan to support not only the shuttle conductors but the surrounding community.

**Safety conductor training and vehicle testing began at the Mcity Test Facility.**

## SCHEDULING

When scheduling conductors, it's important to remember that even though they are "mentally driving" the vehicles, conductors can become tired or bored. Shuttle conductors work approximately four-hour shifts, with three of those hours on-route. The fourth hour includes breaks, plus time for shuttle startup, shutdown, and shift changeover. Operation of the shuttle is currently Monday through Friday, 9 am–3 pm. As the technology continues to evolve and speed increases, shuttle times may expand to meet the community's desire for longer operating hours.

## NON-EMERGENCY ISSUE RESOLUTION

For non-emergency issues, conductors communicate via on-board radios that provide instant communication between conductors, LTP, and Mcity.

## BATTERY CONSTRAINTS

Shuttle operations are suspended when vehicle battery charge declines below manufacturer specification. For example, in hot weather, on-board air conditioning consumption accelerates battery charge depletion, which means shuttles may not complete their six-hour shift. Conductors can avoid this problem by maintaining interior temperatures in-range that is higher than normal but still comfortable, and by charging the vehicle when it is off-route for a conductor break.

## WEATHER CONSTRAINTS

NAVYA recommends that the shuttles not operate in extreme heat or cold. Conductors know to shut down operation when the shuttle's windshield wipers need to run continuously in rain or snow.

## DYNAMIC SHUTTLE TRACKING

In addition to bad weather, construction and changing road conditions can result in suspending operation. A fast, efficient way to inform passengers the shuttles are not running is crucial. We created a website and app where we can post service announcements and show where the two shuttles are on the route at any time. On-board units (OBU) update each shuttle's position, speed, and heading for the DoubleMap mobile and web applications, which augment the data with announcements and scheduling updates so riders have the most recent information.

## OPERATING PROCEDURES

Our goal is to establish consistent behavior among all shuttle conductors. To ensure this, conductors consult operation checklists for shuttle startup, shuttle operation, and shuttle shutdown. If incidents or collisions occur, they have immediate access to step-by-step emergency procedures and vital information such as proof of insurance, government exemption letters, route maps, and shift schedules.

**We created a website and app where we can post service announcements and show where the two shuttles are on the route at any time.**

Mcity's detailed operational procedures cover employee sign-in steps, vehicle cleaning, shuttle startup, running the data-acquisition system, checking route safety, ridership rules, and other parameters. Daily and weekly tasks are delegated to the conductors as part of their startup and shutdown procedures.

## VEHICLE STORAGE

Overnight storage and charging stations are located along the shuttle route to minimize operation outside of the ODD. We obtained a location in a bay area very close to the route, where we installed the high-voltage charging system. The bay also contains a lock box for the shuttle keys and a storage cabinet for cleaning supplies and other equipment. Each day, as operations begin, conductors follow standard operating procedures to manually put the shuttle on the fixed route.

## POSITIONING INFRASTRUCTURE

Shuttles require precise positions, which are obtained from various global navigation satellite systems (GNSS). For the high-precision (1–2cm) accuracy desired, correction data must be collected and delivered to the shuttles via cellular and radio links. Mcity runs a real-time kinematic (RTK) base station, which roughly covers the Ann Arbor area and provides these corrections. This system is used for research purposes as well as shuttle operations.

## ENERGY INFRASTRUCTURE

Shuttles require a 240VAC 40A circuit for fast recharging. This is commonly referred to as "Level 2 charging." Mcity used NEMA 14-50 sockets for maximum future compatibility rather than hardwiring. Quick disconnects were also installed for ease of maintenance. Since these facilities were installed in a commercial building with three-phase power, the circuit actually provides 208V (single phase), which is within spec for the shuttles, while reducing total wattage, which slightly increases charging time.


**Mcity developed clear signage to help passengers identify shuttle stops.**

## ENERGY COSTS

Idaho National Laboratory (INL) has instrumented the charging infrastructure to measure power requirements for the shuttles. They are planning to correlate this data with shuttle distance, acceleration, and heating, ventilation and air conditioning (HVAC) data to build a model of energy usage for low-speed electric shuttles. Initial measurements show energy costs around 30–40kWh ($3.90–$5.20) per day per shuttle, for six hours of daily Michigan summertime operation.

## RIDERSHIP

The shuttle website and signage at the shuttle stops explain the ridership rules, with special emphasis on the safety rules. Ridership is limited to U-M students, faculty, staff, and their escorted guests. For the initial project, children are not allowed to ride the shuttles. Mcity provides the conductors with a continually updated FAQ in order to answer passenger questions.

## ACCESSIBILITY

A primary community who will benefit from the deployment of automated vehicles will be the community of persons with disabilities. Accessibility is essential to large-scale and broad automated vehicle deployment and user adoption. During NHTSA's "Automated Driving Systems (ADS): A Vision for Safety 2.0" unveiling at Mcity, keynote speaker Mark Riccobono, president of the National Federation of the Blind, emphasized that "[e]qual access to affordable, barrier-free transportation is one of the most significant obstacles preventing people with disabilities, who represent one out of every five Americans, from fully contributing talents and achieving full integration in our communities." U-M and Mcity unequivocally agree: the need for accessibility and inclusivity is of the utmost importance to the U-M community. Consequently, Mcity is researching automated vehicle accessibility features and functionality.

Additionally, the university has developed general policies and procedures, and created services to assist our community's persons with disabilities. Among other services, the university offers robust paratransit services for students, faculty, and staff of the university. At the time of shuttle selection for the Mcity research project, no commercially available shuttles existed with adequate accessibility functionality. However, Mcity is working with NAVYA, U-M researchers and other accessibility experts to explore solutions for accessibility modifications and functionality. Moreover, to understand how these new driverless technologies can be designed with broad accessibility in mind, Mcity and its research affiliates desire to open new modes of transportation for all sectors of society, including a growing aging population and the various communities of persons with disabilities.

## OBSTRUCTIONS

Mcity's shuttle operation manager must pay close attention to changes along the route. Construction, delivery vehicles, and other disruptions along the route may cause issues with operations. Shuttle conductors interact with the shuttle operations team and manually maneuver the vehicles around obstructions in the road.

### FIELD NOTE

Be prepared for challenges that arise when operating in less-than-perfect conditions. Your shuttle will be operating in dynamic environments. You have to be responsive to that environment and have robust procedures and communication in place to facilitate smooth operation for the conductors, passengers and other road users.

# 08 Data Acquisition

A comprehensive data acquisition ecosystem was specifically developed for the Mcity driverless shuttle, including sensors, surveys, and network technologies to gain new insights from this research project.

# Data Acquisition

**To maximize the research potential of the Mcity Driverless Shuttle project, we collect data in three areas: shuttle interactions with other road users, behavior of passengers riding the shuttle, and basic vehicle data.**

In addition to objective data collection, we are also working with JD Power to gather feedback from passengers and the surrounding community about their experience with the Mcity shuttles. Those findings will be shared in the future.

Safety considerations precluded interaction with or connection to the sensors the shuttle uses for perception and control. We created a completely separate data collection layer. We turned to our partners at the U-M Transportation Research Institute (UMTRI), whose expertise in vehicle safety research has been honed over more than 50 years. They built, installed, and tested a data acquisition system (DAS) on each shuttle, which we connected to U-M cloud storage via a real-time mesh network for post-processing and analysis.

## SENSORS

### Other road user interactions data

For measuring shuttle interactions with other road users, we added forward and rear-looking video cameras. We also added Mobileye sensors in both views to provide a basic list of vehicles, pedestrians, cyclists, lane markings, and speed limit signs, in addition to speed and heading information for each of them. This metadata is useful for asking questions such as: How many pedestrians crossed in front of the shuttle without making eye contact?

We also added a small button, located near the safety conductor's seat, that can be pressed if the conductor notices "interesting" human behavior. This is obviously quite subjective, but it annotates the data timeline with a marker so we can explore the incident further during analysis.

### Passenger behavior data

To study passenger behavior we added two wide-angle interior cameras and an audio-recording system. These inputs allow us to analyze parameters such as occupancy counts, emotional characterizations, seating position choices, etc. These data are considered personally identifiable information (PII), so their use is governed by the U-M's Institutional Review Board (IRB), which regulates human–subject research. Only specific researchers are granted access to the raw data for specifically approved purposes. For other purposes, PII would be removed before the data are shared more broadly.

**Shuttle vehicle data**

We are also measuring basic information about the shuttles: speed, acceleration and deceleration, yaw, pitch, and door state. These measurements allow us to correlate shuttle behavior with human responses and vice versa.

**To study passenger behavior we added two wide-angle interior cameras and an audio-recording system.**

## DATA ACQUISITION SYSTEM (DAS)

The DAS is the heart of the sensor network. It is responsible for collection, synchronization, and transmission of data to Mcity's cloud systems for later processing. Built to automotive-grade specifications by UMTRI, this system is capable of storing up to two weeks of data on-board in the event of a transmission failure.

## WIRELESS NETWORK & DATA TRANSMISSION PIPELINE

The network connecting the shuttles to U-M systems serves three primary purposes:

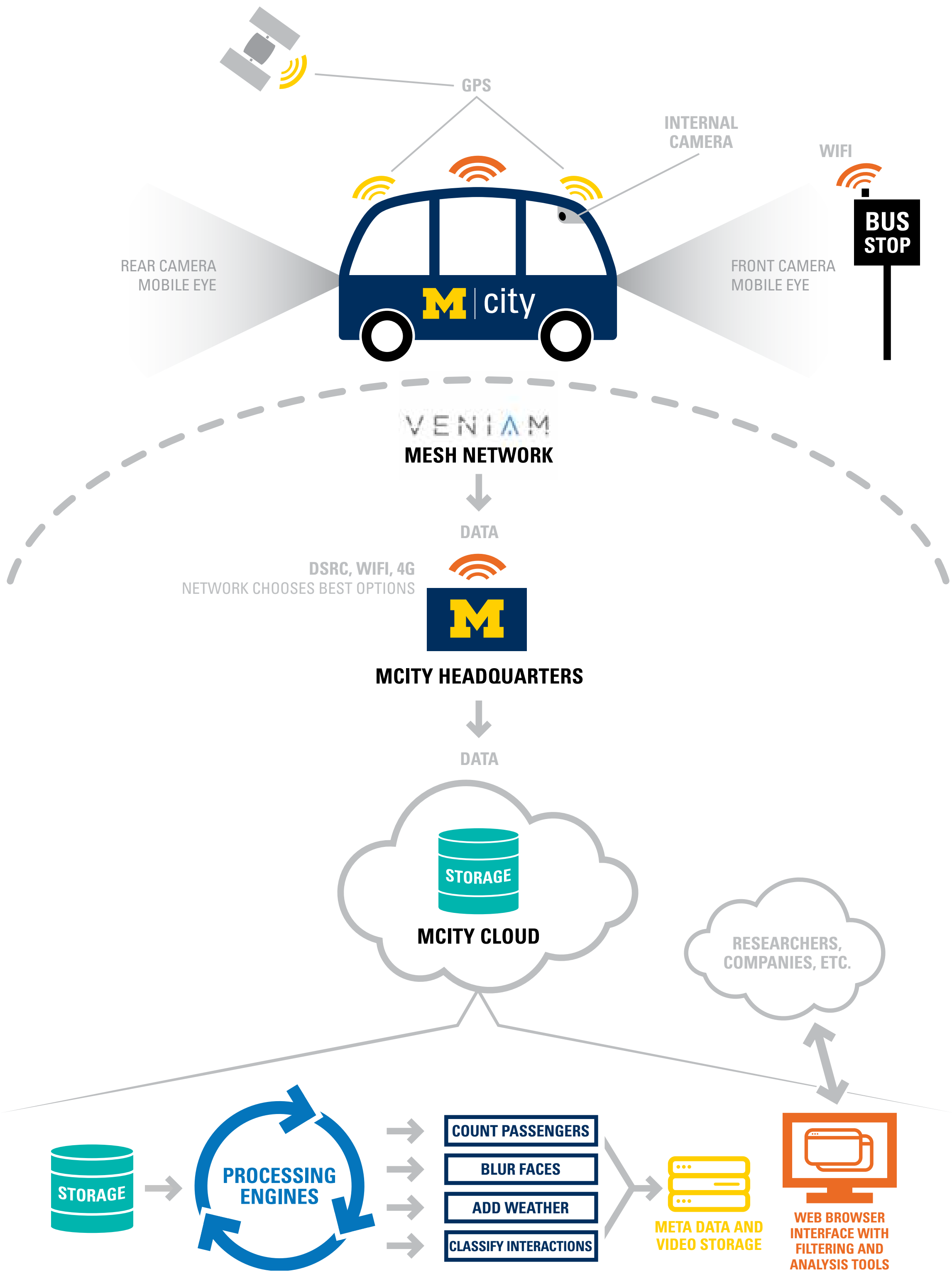
- Real-time operational knowledge
- Offload research data
- In-shuttle campus WiFi for passengers

The Veniam mesh network uses roadside units and nearby shuttles for seamless network access. It provides several techniques for data flow based on availability, such as Dedicated Short-Range Communications (DSRC), LTE, and WiFi, all of which are transparent to the DAS as it transmits information across the network.

**For real-time operational knowledge,** shuttle positions and periodic snapshots from the forward and rear cameras are sent to various systems, including Mcity, the DoubleMap transportation tracker, and U-M LTP operations.

**For research,** collected data are encrypted, and then streamed via secure tunnel to U-M cloud endpoints for post-processing. After transmission, the data are marked for removal from the shuttle's local storage.

**For in-shuttle WiFi,** the network supports a standard U-M WiFi access point (AP) in each shuttle. These APs join the tens of thousands of other APs that make up the campus network. Every time a U-M student, faculty, or staff member uses the network, their access is recorded in a central database run by U-M Information and Technology Services (ITS). This system is made available to researchers for anonymous, aggregate study of things like public transit use, general mobility patterns, and resource utilization. By including the shuttles in this data we hope to be able to study their effect on mobility in their operating environment.




**The Veniam mesh network used by the shuttles collects, synchronizes and transmits data to Mcity's cloud systems for later processing.**

## STORAGE & PROCESSING SYSTEMS

For post-processing, collected data are securely stored in the U-M cloud, where a carefully designed and tested data architecture allows researchers to easily classify vulnerable road user (VRU) behavior patterns related to automated vehicles. The software processes streams of camera and other sensor data captured by the shuttle and extracts metadata about other road users and the environment around the recording vehicle. Extracting semantic data from video allows us to join the video to external datasets and enables our toolset to be used with data collected from basic vehicle video recording systems. The user interface allows vehicle providers, operators, and researchers to identify, filter, annotate, and display specific types of road-user behavior and interactions. Constructing sets of VRU patterns creates a springboard for deeper exploration of system design and user response to vehicle actions, as well as investigation into how these behaviors may change over time with repeated exposure to the technology.

**The mesh network uses roadside units and nearby shuttles for seamless network access.**

## END GOALS FOR DATASETS

The main goal of this research project is to collect data that will be used to understand trust and behavior of both shuttle riders and other road users along and near the shuttle's path. We estimate that this one-year project will produce data from about 7,500 vehicle miles, provide mobility to 10,000 riders, interact with 10,000 road users, and generate 1,500 effective user surveys. After the data are processed for quality and privacy protection, they will be shared with Mcity industrial members and U-M researchers to enhance understanding of human interaction with driverless vehicle technology.

### FIELD NOTES

**Define desired data needs early, and devise a data collection method that does not interact or interfere with the sensors used by the shuttle for perception and control. This must be done while preserving privacy.**


**Data acquisition is a crucial component of the Mcity Driverless Shuttle research project. We estimate producing data from about 7,500 vehicle miles during the one-year initiative.**

# 09 Incident Response Plan

Mcity created, tested, evaluated, and documented emergency scenarios before real-world deployment.

# Incident Response Plan

Mcity carefully analyzed how to manage possible emergency situations. Safety conductors received extensive training, and Mcity staff developed emergency plans. U-M and federal, state and local stakeholders were briefed on incident response procedures and participated in mock crash scenarios.

Engaging a wide variety of stakeholders in an emergency response plan is essential. The range of possible incidents extends from small problems (scraping the side of the garage door, a passenger incident on the shuttle), to more serious situations (collisions, injuries, and fatalities).

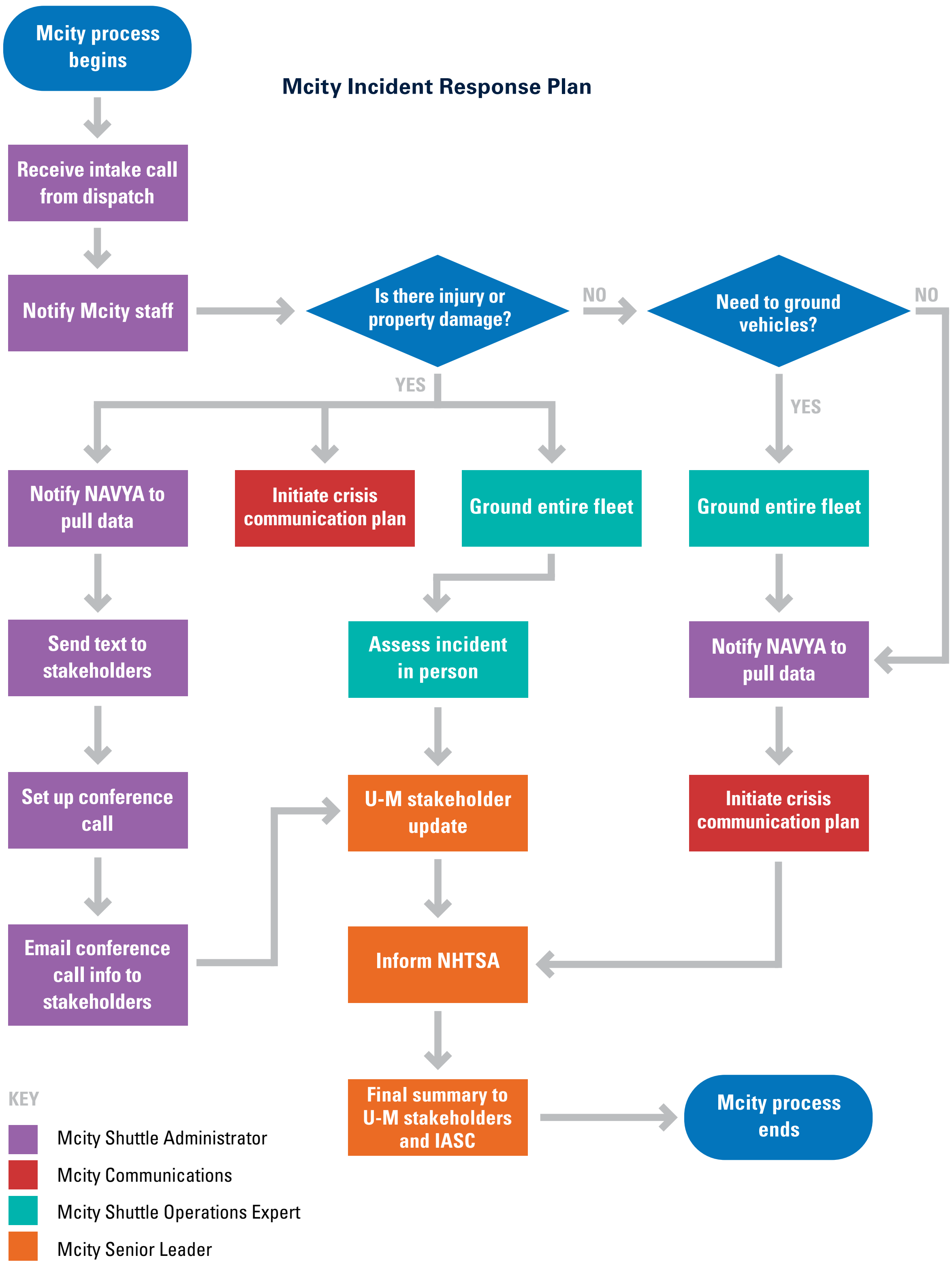
**University stakeholders include:**

- Mcity
- Logistics, Transportation & Parking (LTP)
- Risk Management
- Department of Public Safety and Security (first responder)
- Office of the General Counsel
- Office of the Vice President for Communications
- Environment, Health & Safety

There's no way to plan for every possible incident in a complex traffic environment. You'll never be prepared for everything that could happen. The next best thing is to practice. We did that repeatedly to refine Mcity's response plan.

**A mirror located inside each shuttle helps the on-board safety conductor see what's happening behind them.**


**Mcity Driverless Shuttle safety conductors, along with Mcity staff members, were trained in how to respond to incidents involving the shuttles.**




**The Mcity Incident Response plan assigns specific responsibilities to Mcity staff to speed communication with key stakeholders and coordination on a response in the event of a crash or other incident along the shuttle route.**

### Create a Plan

Incident response planning began with a mock crash involving university stakeholders. Several mock-crash scenarios were identified and analyzed, focusing on action items that each stakeholder would need to execute in the event of an emergency. The results led to a first draft of process flow, which was shared among stakeholders. Then we hosted an event with NHTSA, to review crash scenarios again, focusing on what type of information and actions the agency would require. Prior to the launch of the low-speed shuttle, we staged a second mock crash at the Mcity Test Facility and used the results to establish a final process flow.

## You'll never be prepared for everything that could happen. The next best thing is to practice. We did that repeatedly to refine Mcity's response plan.

### Incident response plan includes:

- Emergency process and script for safety conductors, including lock-out procedures for the high-voltage battery and an incident reporting process
- Emergency process and script for LTP dispatchers
- Detailed plan for Mcity staff
- Mcity-designed software-enabled automation of stakeholder notification for rapid communication to a large group
- Incident-level definitions for stakeholder communication
- Grounding protocol and process for the vehicles
- NHTSA notification process template
- Detailed communication plan
- Detailed map of the route for all stakeholders
- Initial emergency phone conference script for all stakeholders

FIELD NOTE

**Exhaustive emergency preparation is essential when deploying driverless shuttles. Any emergency will require an immediate, well-executed response appropriate to the severity of the incident. All stakeholders must understand their role in an emergency through training and practice.**

# Lessons from Mcity
## Summary

One of Mcity's top goals has always been to launch a driverless vehicle project on the U-M campus. We just needed the right vehicle.

In December 2016, French firm NAVYA introduced its Arma driverless shuttle – now known as the Autonom Shuttle – to North America at Mcity. By May 2017, our experience operating NAVYA's shuttle inside the Mcity Test Facility gave us the confidence to begin earnest discussions with key stakeholders about a campus deployment.

In June 2018, two Mcity driverless shuttles hit the road as part of a research project to learn more about how consumers react to and interact with automated shuttles, be it as a passenger, or as a pedestrian, bicyclist, or driver sharing the road with the shuttles.

Through this case study, Mcity hopes that sharing the lessons we learned along the way will help other organizations who may be considering launching driverless shuttle services. What Mcity learned applies not just to academic research projects like ours, but also to real-world shuttle deployments.

**Set Specific Project Goals**
The Mcity Driverless Shuttle project was designed to achieve the specific research goal of understanding passenger and road user behavior while ensuring a safe deployment. Research needs and safety shaped the route environment, data acquisition, and operational plan.

**Engage Stakeholders Early**
Identify key stakeholders early in the process of considering a shuttle deployment, and engage them often through planning and after launch. Their insights are invaluable and they can flag potential obstacles before they slow down progress.

**Explore Legal, Regulatory, and Insurance Questions**
To the extent possible, seek to engage federal, state, and local government authorities early, even as early as the planning stages. View government regulators as collaborators as their advice is often invaluable. NHTSA provided guidance regarding automated vehicles in 2017, titled "Automated Driving Systems (ADS): A Vision for Safety 2.0". U.S. Transportation Secretary Elaine Chao announced the guidance at Mcity.


**U.S. Transportation Secretary Elaine Chao announces updated federal guidance for automated vehicles at Mcity in September 2017.**

Connect with institutional and community stakeholders at the outset as preliminary planning and development may require significant lead times for insurance and risk managers, legal counsel, transportation authorities, and others.

### Identify Operational Environment Constraints

There are many constraints in developing an operating environment, known as the Operational Design Domain (ODD), for low-speed shuttles. Careful consideration must be given to a variety of parameters prior to launch. During operation it is important to remember that you must constantly monitor these dynamic parameters, including weather, roadway and traffic conditions, and construction. Any changes could conflict with the defined ODD.

### Conduct Your Own Testing

Having a separate evaluation either by your organization or a third party is an important step in evaluating a driverless shuttle for your ODD.


**The Mcity Driverless Shuttle project uses two NAVYA Autonom electric shuttles.**

### Train Safety Conductors Thoroughly

We found it important to have a careful progression of training for on-board safety conductors. Beginning in a closed testing site – the Mcity Test Facility – allowed conductors to build confidence safely, only moving into real traffic conditions once they had demonstrated their proficiency.

**Mcity Driverless Shuttle safety conductors complete at least 14 hours of training in operating the shuttle inside the Mcity Test Facility, followed by two weeks of training on the shuttle route.**

### Anticipate Challenges

Be prepared for problems that arise when operating in less-than-perfect conditions. Your shuttle will be running in dynamic environments. You have to be responsive to that environment and have robust procedures and communication in place to facilitate smooth operation for the conductors, passengers, and other road users.

### Develop an Incident Response Plan

Exhaustive emergency preparation is essential when deploying driverless shuttles. Any emergency will require an immediate, well-executed response appropriate to the severity of the incident. All stakeholders must understand their role in an emergency through training and practice.

### Establish Data Needs Early

Define desired data needs early, and devise a data collection method that does not interact or interfere with the sensors used by the shuttle for perception and control. This must be done while preserving privacy.

### A Final Note

Any organization that embarks on driverless shuttle deployment should not begin without a clear understanding of what is involved. Mcity hopes this document can serve as a kind of guidepost along the way.

# Thank You

The Mcity Driverless Shuttle research project came to fruition through the contributions of many key partners within the University of Michigan:

**Office of Research**
**Transportation Research Institute**
**Office of the Vice President and General Counsel**
**Logistics, Transportation & Parking**
**Risk Management**
**Government Relations**
**College of Engineering**
**Institutional Autonomous Systems Committee**
**Institutional Review Board**
**Division of Public Safety & Security**
**North Campus Research Complex community**

And thanks to these Mcity partners:

**Mcity Leadership Circle and Affiliate members, with a special thanks to NAVYA and JD Power**
**Office of Michigan Secretary of State**
**Michigan Department of Transportation**
**Michigan Council on Future Mobility**
**City of Ann Arbor**
**Ann Arbor Area Transportation Authority**
**Ann Arbor Police Department**
**Ann Arbor Public Schools**

LEADING THE TRANSFORMATION
TO CONNECTED AND AUTOMATED VEHICLES

Mcity at the University of Michigan is leading the transition to connected and automated vehicles. Home to world-renowned researchers, a one-of-a-kind test facility, and on-road deployments, Mcity brings together industry, government, and academia to improve transportation safety, sustainability, and accessibility for the benefit of society.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