



MSU MOBILITY PLAN

Michigan State University's Mobility Plan initiative comprises mobility technology, mobility source management, and infrastructure. The combination of these collective efforts will result in the weaving of a mobility tapestry that will serve as a comprehensive and adaptable roadmap to guide and position MSU as a recognized leader in mobility, both nationally and globally. The MSU Mobility Technology Committee, the MSU Mobility Source Management Committee, and the MSU Infrastructure Committee summarize their work in the following report.

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EXECUTIVE SUMMARY

Michigan State University is home to approximately 39,000 undergraduate and 11,000 graduate and professional students from every county in Michigan, every state in the nation, and over 130 countries around the globe. Approximately 14,500 of these students reside on campus in 27 campus residence halls and 2 apartment communities. The university employs approximately 5,700 faculty and academic staff, as well as 7,100 support staff.

The campus consists of 2,100 acres of developed land and 3,200 acres of undeveloped or farm land. Standing on our campus are over 550 buildings, including 106 major buildings with academic or instructional spaces.

In almost every sense MSU's campus is a city of its own. The campus contains 57 lane miles of roadways, 20 miles of dedicated bike paths, and 113 miles of pedestrian walkways and sidewalks. Traffic flow is regulated by 37 networked traffic lights with traffic monitoring hardware and software. MSU's own police force has 85 members and provides flexibility in managing traffic flow.

Over 9,200 employee parking permits, over 2,000 student parking permits, and over 1,600 commercial parking permits are issued in a typical year. Additionally, over 7,900 bicycles are registered on campus. The university owns over 1,000 service vehicles, 170 of which are equipped with GPS locating devices.

During instructional days, between the hours of 8 am and 6 pm, every hour is rush hour during the 20-minute periods between classes. Many thousands of students, faculty and staff have to move between classes in different buildings. Most of them walk, but many use bikes, mopeds, and cars. Many students and some employees also ride the bus, with bus service provided by the Capital Area Transportation Authority (CATA). CATA provides almost 37,000 hours of bus service on campus in a year, and approximately 2.7 million individual bus rides are taken on campus each year.

A large number of visitors come to MSU. These visitors range from vendors to parents of the students, from school children to community groups, from construction workers and contractors to service and delivery drivers. Approximately 63,000 visitor day parking permits are issued to those guests per year.

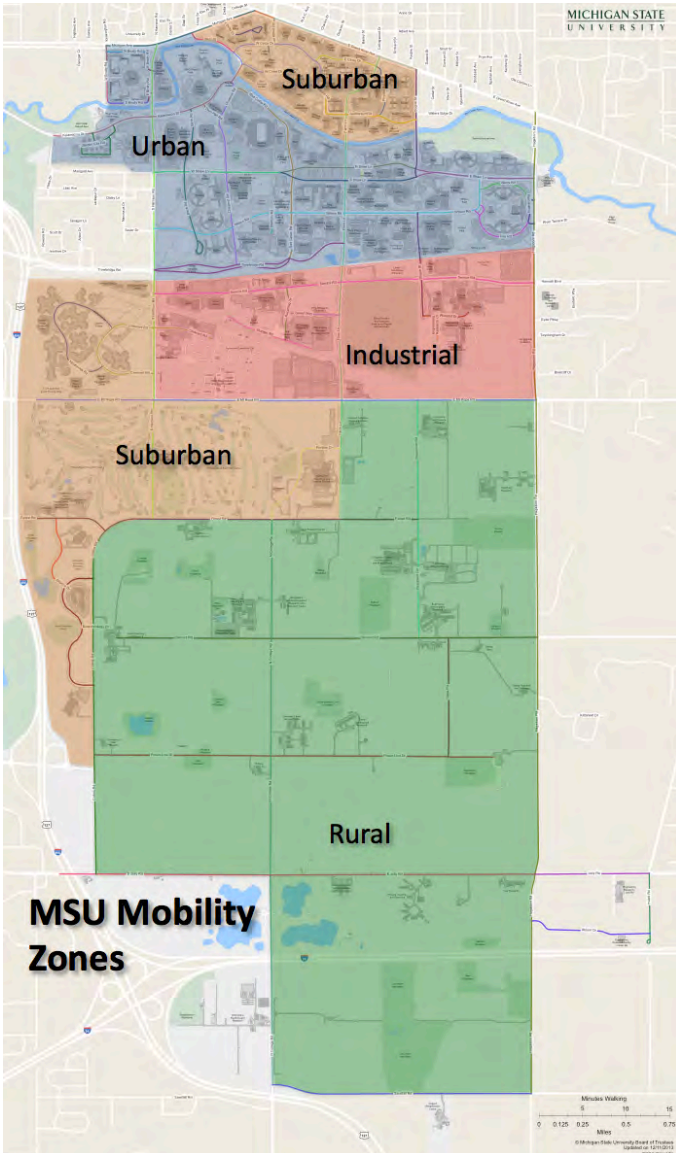
An even larger group of campus visitors are attracted to campus during football and basketball home games, other MSU varsity sports, high school tournaments, conferences in the Henry Center and Kellogg Center, and occasional concerts, events, and performances in Wharton Center, the Fairchild Auditorium, the MSU Pavilion, Breslin Center, and Spartan Stadium. During many of these events special provisions to regulate campus traffic have to be in place.

Traffic density varies greatly. In the historic part of campus north of the Red Cedar River, as well as in Spartan Village and around the two MSU championship golf courses and the MSU technology park, one finds suburban traffic conditions, with significant green space between buildings. The area just south of the river is densely packed with major research and instructional buildings and has pedestrian and vehicular traffic usually seen in central urban environments. The area around the Power Plant and Clinical Center houses various university services, as well as large parking lots, and shows traffic patterns found in industrial zones. Finally, the campus area south of Mt. Hope Road can be described as rural, with farm fields and forests, occasionally dotted with farm buildings. Therefore, MSU's campus is an ideal proving ground for new ideas in traffic engineering, in particular in connection with emerging autonomous vehicle technology. MSU owns the infrastructure and can thus create perfect testing conditions, in which research can be done in a controlled manner. The campus map shown on the next page delineates the various traffic zones and their approximate boundaries.

A mobility campus survey of employees was conducted in 2017 and had an excellent response rate. A total of 2,571 survey responses was received. Some of the highlights include that over 89% of employees use their personal vehicle for their daily commute, 35% indicate that they move their car during lunch hour, and 39%

responded that they move their car for meetings on a daily basis. Arrival and departure time distributions show strong peaks around 8 am and again at 5 pm.

Safety for all MSU campus community members and visitors is the highest priority. Avoiding traffic accidents thus is paramount. This document explores a wide variety of possible solutions for all mobility participants.



- **Mopeds:** The last few years have seen a strong increase in the number of mopeds on campus, which share the road with cars, but also the bike paths with bicycles, and often even the walkways with pedestrians. Finding solutions to allow all of these vehicles and pedestrians to coexist without interfering with each other is of highest importance.
- **Cars:** Reducing the number of cars moving across campus at any given time decreases congestion, allows for more rapid movement, and decreases accidents. Moving parking to the campus perimeter, introducing dedicated parking spots for each permit holder, enabling more virtual meeting options for on-campus meetings, and increasing the attractiveness of other modes of transportation (bike share, bus, car pool) are all considered.
- **Pedestrians and bicycles:** Commuting distances between classes can be shortened and will alleviate congestion during class change periods. Application of Big Data Analytics can help. The concentration of class offerings between 10 am and 3pm causes additional congestion and should be softened. Technical capabilities to provide dedicated wayfinding services will be implemented.
- **Public Transportation:** CATA buses offer rides to the MSU community, which are subsidized by MSU funds. But this mass campus transportation is underutilized. Free rides for students, better connections to the multi-modal transportation hub, more precise bus GPS localization, a dedicated CATA bus app, and route modifications are all possible improvements discussed in this report.

Autonomous vehicles will arrive on campus in the near future. As one of the top-100 universities in the world MSU has an obligation to lead in this development, in order to make sure that autonomous technologies are implemented in such a way that safety, convenience, and affordability are increased. The campus, with its varied zones of traffic density, is an ideal testing ground for the interaction of autonomous vehicles with each other, with the infrastructure backbone, and with humans. Vehicle-to-infrastructure communication is paramount and is presently being implemented on campus. Research projects like CANVAS and the Mobility Studio are partnering with industry leaders to develop autonomous vehicle technology and smart infrastructure, connected to the policy and social aspects of the human experience. This will result in reduced traffic congestion, smarter parking systems, and higher campus safety for all mobility participants.

MSU's Mobility Plan will enhance mobility and convenience, improve the on-campus experiences for members of the MSU community and those who visit our campus, while influencing behavior and finding new ways to optimize mobility, and positioning MSU as a recognized mobility leader. With each phase of implementation, opportunities will increase for student success that provide a high-quality educational and work environment, while increasing safety and promoting positive on-campus experiences for students, faculty, staff, and visitors. MSU's Mobility Plan is designed to encourage environmentally sound practices, while supporting cutting-edge research. Our initial efforts demonstrate that the answers and solutions to improved campus mobility lie in the creativity and innovation of MSU faculty, staff, and students. The MSU culture provides the foundation for imagining and then implementing a broad range of changes across campus, changes that will not only improve mobility, but also student success and work-life balance.

The infrastructure section provides a working outline for addressing near-term and long-term infrastructure and planning needs in a sustainable mobility format. Student, employee and visitor safety is the overriding concern with each of the three work steps presented and their implementation process. Sustainable mobility planning and management practices that focus on safety are recommended. Sustainable planning requires more long-term social interaction to better understand stakeholder needs and wants. These are necessary elements to make sure that resulting plans, policies and rules will be adopted and adhered to over time (e.g., surveys, focus groups, program assessments, outreach and research). The methods that MSU currently uses to manage its infrastructure need to be updated to include "what if" GIS modeling combined with current relational data bases that allow all decision makers from technicians to Board of Trustee members to have the same information and the same probable outcomes prior to making a final decision (e.g., examples are provided). This system requires a different management model (i.e., ALERT) to be successful. A process for integrating infrastructure decisions, management and work with class scheduling, student and employee movement on campus, services, campus deliveries, health programs, athletics, etc., is provided. This is a critical near-term need if the system is to be sustainable.

It should be noted that MSU's infrastructure management isn't broken. MSU, as most other major universities that want sustainable and efficient mobility systems, needs to adopt new technology, research and outreach methods described in this section to be successful.

MSU has a chance to occupy a unique leadership position in establishing a real-world test track under controllable conditions in the Spartan Village section of campus. By gating the 330-acre facility off, a controlled system can ensure safety while enabling testing new hardware and software to high confidence levels, before bringing it to the public environment. New technologies in vehicle automation algorithms, mapping, sensors including radar technologies up to mm wave frequencies, and sensor fusion technologies, parking algorithms, roadway sensors, signal light cameras with vehicle, bicycle, and pedestrian recognition and management can be tested at this site in ways not currently available elsewhere. Additionally, development of lightweight low-speed vehicles of golf cart size or smaller provide an opportunity for differentiation and mobility enhancement. Installation of new parking technology infrastructure can provide parking availability while minimizing searching; campus buildout of this system should be completed. Finally, MSU should seek opportunities to partner with DSRC, 5G, and other high bandwidth providers to implement cutting-edge wireless infrastructure on campus, which will enable leading vehicle-infrastructure-person communication in the autonomous transportation future.

Research beyond the engineering and science disciplines is needed for an autonomous vehicle future as well. To this end MSU should prioritize research on societal implications of an autonomous transportation future in the fields such as law, urban design, human-machine interaction, actuarial science, economics, and other social sciences.

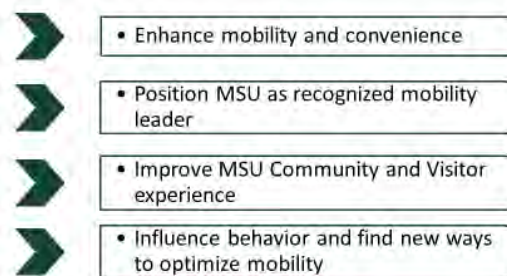
MOBILITY SOURCE MANAGEMENT

MSU MOBILITY SOURCE MANAGEMENT COMMITTEE

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OVERVIEW

The guiding principle for the Mobility Source Management Committee is best represented by this question: “Can we change and alter behavior of Michigan State University’s internal and external communities regarding the challenges and opportunities presented by campus mobility?” Those challenges and opportunities exist in a variety of ways that encompass campus pedestrian traffic, bike and motorized traffic, and traffic ebbs and flows driven by class changes, workday hours, deliveries, game-day activities, and many other campus events/activities.



In addition to the mobility source management guiding principle, there are several basic principles that have guided—and will continue to guide—the process. Those principles include seeking solutions fueled by stakeholder input to improve mobility on campus, using data-driven analytics as a foundation for conceptualizing solutions/initiatives, contributing to and improving student success, and providing for collaboration/partnerships among a variety of entities and individuals across the MSU community.

Several themes that have emerged from review of data sources, including class schedules, a recently conducted MSU Mobility Survey, a new Employee Location Mapping initiative, and requests for the generation of additional data, including analysis of MSU’s information technology capabilities regarding support of virtual meetings.

There is also a commitment regarding academic/research opportunities related to mobility planning that has its foundation in MSU serving as a living test-bed that connects teaching and research with practice, policy, and economic development. MSU has a unique opportunity to explore improvements in mobility in tandem with exploring ways to improve student success, as advances in one area will be intrinsically beneficial to the other. Additionally, undergraduate and graduate research opportunities can significantly contribute to the goal of MSU being recognized as a leader in mobility.

MSU MOBILITY SURVEY

SURVEY RATIONALE

Recent efforts across campus have focused on mobility planning that will improve traffic safety, decrease commuting times, enhance infrastructure, and integrate scholarship and teaching into solving mobility problems. As part of the university-wide effort to draft a master plan for campus mobility, the Office of the Associate Provost for Academic Services, Enrollment Management, and Academic Initiatives administered the MSU Mobility Survey to MSU employees during summer 2017. The rationale behind conducting such a survey was to help identify and guide implementation of changes that will:

- Enhance mobility and convenience
- Position MSU as a recognized mobility leader
- Improve MSU community and visitor experiences
- Influence behavior and find new ways to optimize mobility

In addition to the rationale directly related to mobility planning, making positive, campus-wide improvements related to mobility will also:

- Increase student success
- Provide a high-quality educational and work environment
- Increase safety
- Promote positive on-campus experiences for students, faculty, staff, and visitors
- Encourage environmentally sound practices
- Support cutting-edge research

SURVEY REVIEW AND ANALYSIS

The review and analysis of survey data and potential deliverables was undertaken in conjunction with a number of units across campus. A collaborative approach to understanding and interpreting the data helped ensure the solid identification of robust and comprehensive deliverables to provide the greatest impact across campus. The MSU WorkLife Office, IT Services, and Infrastructure Planning and Facilities collaborated across units toward the larger, university-wide goals of mobility planning, reaching out to engage appropriate partners and existing resources at each turn.

Proposed deliverables are data-driven and evidence-based, using both survey data and existing institutional data.

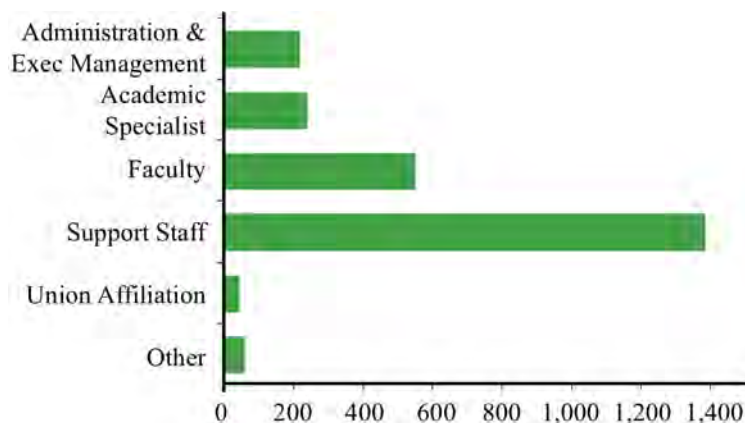
SURVEY POPULATION

On July 12, 2017, the MSU Mobility Survey was sent to approximately 11,000 MSU faculty and staff employees who work on the East Lansing campus. Recipients were informed that the survey was confidential and anonymous. A survey reminder was sent on July 24, 2017, with a response deadline of July 31, 2017.

A total of 2,571 survey responses were received from all major administrative units on campus, with the largest number of responses from the College of Agriculture and Natural Resources (230), College of Natural Science (206), College of Social Science (145), Infrastructure Planning and Facilities (142), and Residential and Hospitality Services (131). Fifty-five percent of respondents self-identified as support staff, 22 percent as faculty, 10 percent

as academic specialist, and 9 percent as administration/executive management.

Q12 - Which job category best describes your position?



MOVEMENT, TRANSPORTATION, AND DISTANCE

Thirty-five percent of survey respondents indicated they move their car during the lunch hour; even more, 39 percent, move their car at some point during the workday to attend meetings.

Q5 - Do you typically move your car during the workday? (check all that apply)

#	Answer	%	Count
1	Yes - during lunch hour	35.33%	721
2	Yes - to attend meetings	38.56%	787
3	Yes - other times/other reasons	26.11%	533
	Total	100%	2041

Employees who move their car or leave campus for some reason during the day may return and not be able to find a parking spot. This is not only stressful but also takes time and focus away from work-related activities and responsibilities. Anecdotally, the WorkLife Office reports that faculty and staff especially struggle with their ability to commute on and around campus and dread meetings or professional development opportunities that require them to move their vehicle during the day.

This is a work-life issue for two reasons. The first is that on-campus traffic congestion may be causing unnecessary stress for faculty and staff whose job responsibilities require them to attend meetings or other work functions throughout campus or off campus. The second is that “green” and healthy commuting options will positively impact the well-being of MSU’s faculty and staff, thereby increasing the high-performance capacity of those individuals.

The primary mode of transportation is overwhelmingly a personal vehicle, at 89 percent, which contributes to congestion and limited parking availability on campus. The next closest mode of transportation is bike, at 4 percent.

Q6 - What is your typical mode of transportation to get to work most days?

#	Answer	%	Count
1	Personal vehicle	89.13%	2279
2	Walk	2.23%	57
3	Dropped off by another personal vehicle	1.68%	43
4	Bike	4.38%	112
5	Bus	1.33%	34
6	Moped/scooter	0.23%	6
7	Carpool group	0.86%	22
8	Michivan Ride Share service	0.16%	4
	Total	100%	2557

Eighty percent of respondents indicated that they commute within 25 miles of campus.

Q7 - Do you commute more than 25 miles each way to work from home?

#	Answer	%	Count
1	Yes	20.02%	512
2	No	79.98%	2045
	Total	100%	2557

It may prove valuable in a future survey to ask respondents if they live within five miles of campus, and then to ask those who do and use a personal vehicle why they do not choose to bike, walk, or take a bus to and from campus.

Only 39 percent of respondents indicated that they are aware of the Capital Area Transportation Authority (CATA) bus service, which provides free rides on campus to those with an employee ID. Twenty-six percent indicated that they are aware of the rental and repair offerings through MSU Bikes Services. Other services, such as Michivan Ride Share, CATA Clean Commute carpooling, and reduced parking fees for carpoolers, are much less known.

It is clear that opportunities to educate members of the MSU community could bring about greater awareness of services available in support of travel to and from campus in addition to driving a personal vehicle.

FLEXIBLE SCHEDULES/WORKING REMOTELY

Almost half of survey respondents indicated that they work a flexible schedule or that they work remotely at times. Of those respondents, 78 percent would like to increase their flexible schedule or work remotely more often, and 73 percent anticipate that their supervisor would be supportive of such a request.

Q9b - If you could increase your flexible schedule or work remotely more often and it was feasible given your job responsibilities, would you be interested?

#	Answer	%	Count
1	Yes	78.24%	978
2	No	21.76%	272
	Total	100%	1250

Of the 51 percent of survey respondents who do not currently have a flexible schedule or work remotely at times, 82 percent are interested in such flexibility. However, 57 percent anticipate that their supervisor would not support such a request.

Q10a - If you made a request to work a flexible schedule or work remotely, do you anticipate that your supervisor would be supportive?

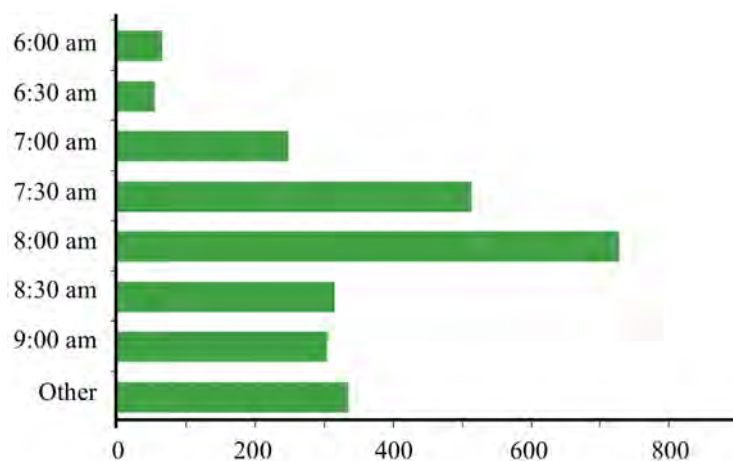
#	Answer	%	Count
1	Yes	42.70%	550
2	No	57.30%	738
	Total	100%	1288

It could be deduced from this data that supervisors who have allowed staff some degree of a flexible schedule and/or working remotely see the value of granting such a schedule and are more apt to allow it to continue and/or increase the degree of flexibility. Supervisors who have not granted flexible scheduling could be less likely to consider adopting any degree of scheduling flexibility. The university may benefit from providing additional education and incentives to encourage increased granting of both flexible scheduling and working remotely.

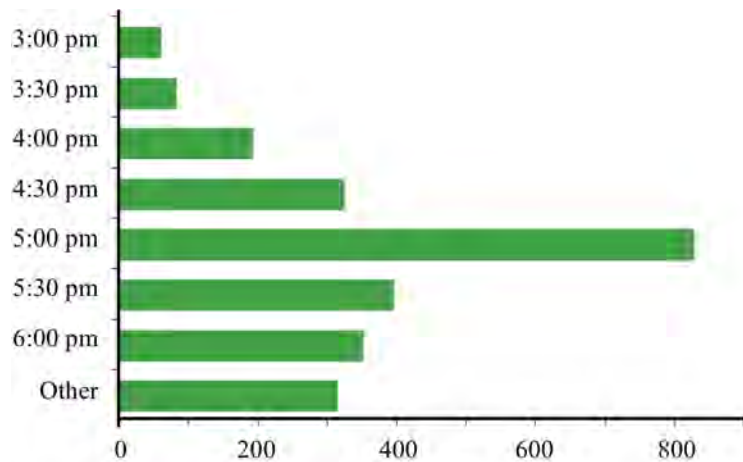
ARRIVAL/DEPARTURE TIMES

Most employees work Monday through Friday, with fewer than 2 percent of respondents working on Sunday and Saturday. Nearly half start their day between 7:30 and 8 a.m. and end their day between 5 and 5:30 p.m. The highest percentage of survey respondents, 28 percent, arrive on campus at 8 a.m. The highest percentage of survey respondents, 32 percent, depart from campus at 5 p.m.

Q3 - What is your typical arrival time?



Q4 - What is your typical departure time?



Implementation of a broader range of start and stop times for a typical workday could result in decreased campus congestion around peak travel times. Additionally, the use of flex-time and remote working from home could help reduce campus congestion and increase safety for pedestrians and bicyclists. This represents a significant opportunity to improve not only campus mobility but also employee satisfaction.

ISSUES RELEVANT TO EMPLOYEES

MSU's WorkLife Office is invested in supporting the development of more efficient and varied commuting options for MSU employees. In conjunction with the Mobility Task Force, the WorkLife Office is committed to gaining insight into the trends for commuting on campus with the goals of understanding the commuting needs of the MSU community, exploring the options already available to MSU's faculty and staff for efficiently getting to work each day, and ultimately reducing stress associated with commuting in order to increase productivity. With employees commuting from greater distances, the impact on success and productivity at work is of particular interest to the WorkLife Office, due to its mandate to enhance the success, engagement, and productivity of faculty and staff.

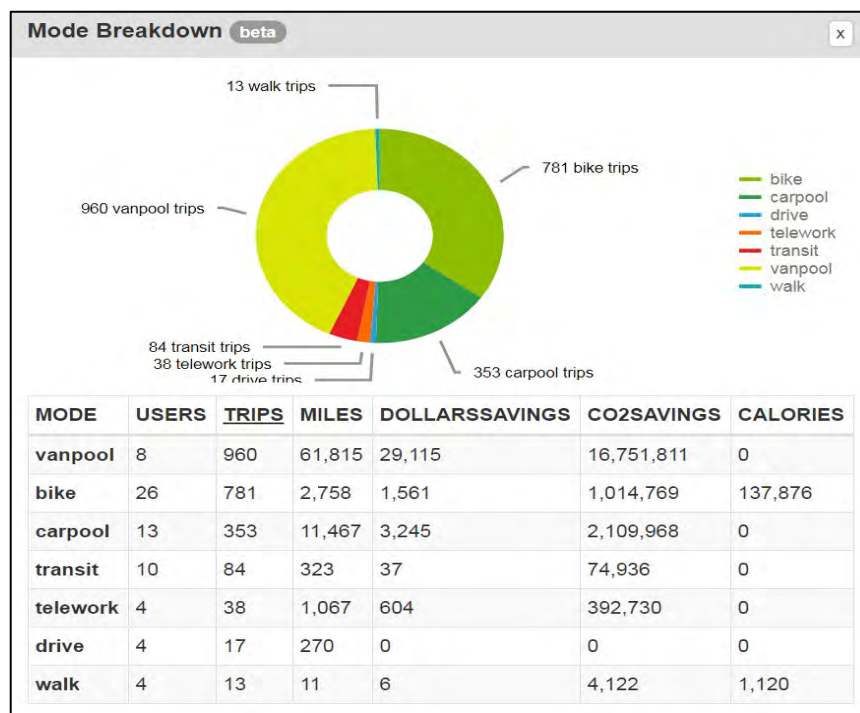
Another finding that is of particular interest to the WorkLife Office is that nearly half of respondents currently flex their schedule. Flexible work arrangements increase productivity and increase the retention of MSU's best and brightest faculty and staff. Flexible work arrangements also contribute to a reduction in 8 a.m. and 5 p.m. traffic congestion. When people stagger their work hours or telecommute, they reduce time spent in traffic jams or searching for parking.

The WorkLife Office is dedicated to helping MSU faculty and staff find the commuting options that are available to them and identify the commuting mode that is best suited to their needs. To that end, educational panels regarding commuting have been organized, a commuting resources web page has been created, and options have been offered during one-on-one and department consultations. The goal is to encourage alternative commuting options in order to increase productivity in the workplace.

By increasing the utilization of "green" commuting options, such as Michivan Ride Share, carpooling, biking, CATA campus routes, and walking, it will be possible to reduce campus congestion and unnecessary employee stress, which will benefit the environment and the MSU community.

COMMUTER DATA

Chloe White, CATA's Clean Commute Options coordinator, assembled the following chart on October 5, 2017, for use by MSU's WorkLife Office. Included is data for the 113 MSU commuters who are enrolled with CATA's Clean Commute Options (CCO), 52 of whom actively report their commute information on CCO's RideAmigos website. CO₂ savings are reported in grams, and a trip is equivalent to one-way travel.



Only 1 percent of survey respondents indicated that they get to campus via a carpool or use Michivan Ride Share, yet 20 percent of them drive more than 25 miles a day to get to campus, which provides a great opportunity to try to recruit more people to commute. The WorkLife Office recently launched the MSU Fall Commuter Challenge for people to compete with one another on campus; it ran until December 15, 2017.

The WorkLife Office continues to promote commuting initiatives and has posted information in support of commuting on the web at <https://worklife.msu.edu/commuting-resources>. The office is also exploring with Human Resources the feasibility for van ride share and Michigan Flyer commuters to use pretax payroll deductions from WageWorks.

Overall, survey responses make it clear that there are multiple opportunities to improve campus mobility that will inherently improve other aspects of campus work and life. Creative approaches to thinking about ways to diversify ingrained approaches to setting work hours—and in choosing modes of transportation—have the potential to make transformative changes in support of campus mobility.

ISSUES RELEVANT TO STUDENTS

The Office of the Associate Provost for Undergraduate Education (APUE), in collaboration with IT Services, Office of Planning and Budget's (OPB) Institutional Studies, and the Registrar's Office, has undertaken a comprehensive effort to identify and ameliorate barriers to student success at MSU. The effort, led by the Learning Analytics Group based in the APUE and the Hub for Innovation in Learning and Technology, is pursuing a coordinated

program to bring to light the structural obstacles that slow students' progress to graduation, that increase the cost of their degrees, or that differentially impact subgroups of students.

Analysis of MSU data demonstrated a significant decrease in six-year graduation rates for students who enrolled in fewer than 15 credits in their first fall semester at MSU and who did not complete 30 credits prior to the fall semester of their second year. These findings held true across all genders, races, and ethnicities of students, which motivated the APUE to launch the Go Green, Go 15 campaign [Figure 1], a coordinated communication effort to increase students' credit loads, especially in their first semester at MSU.

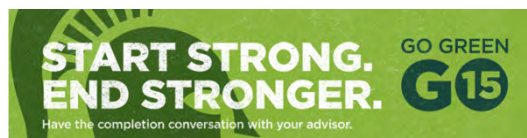


Figure 1: An example of the messaging associated with Go Green, Go 15

This effort resulted in a 50.3 percent increase in the percentage (from 28 percent to 42 percent) of students who enrolled in 15 or more credits in their first fall semester at MSU, which amounted to nearly 10,000 additional credits being taken by the 2017 incoming cohort of students compared to the previous year's incoming cohort.

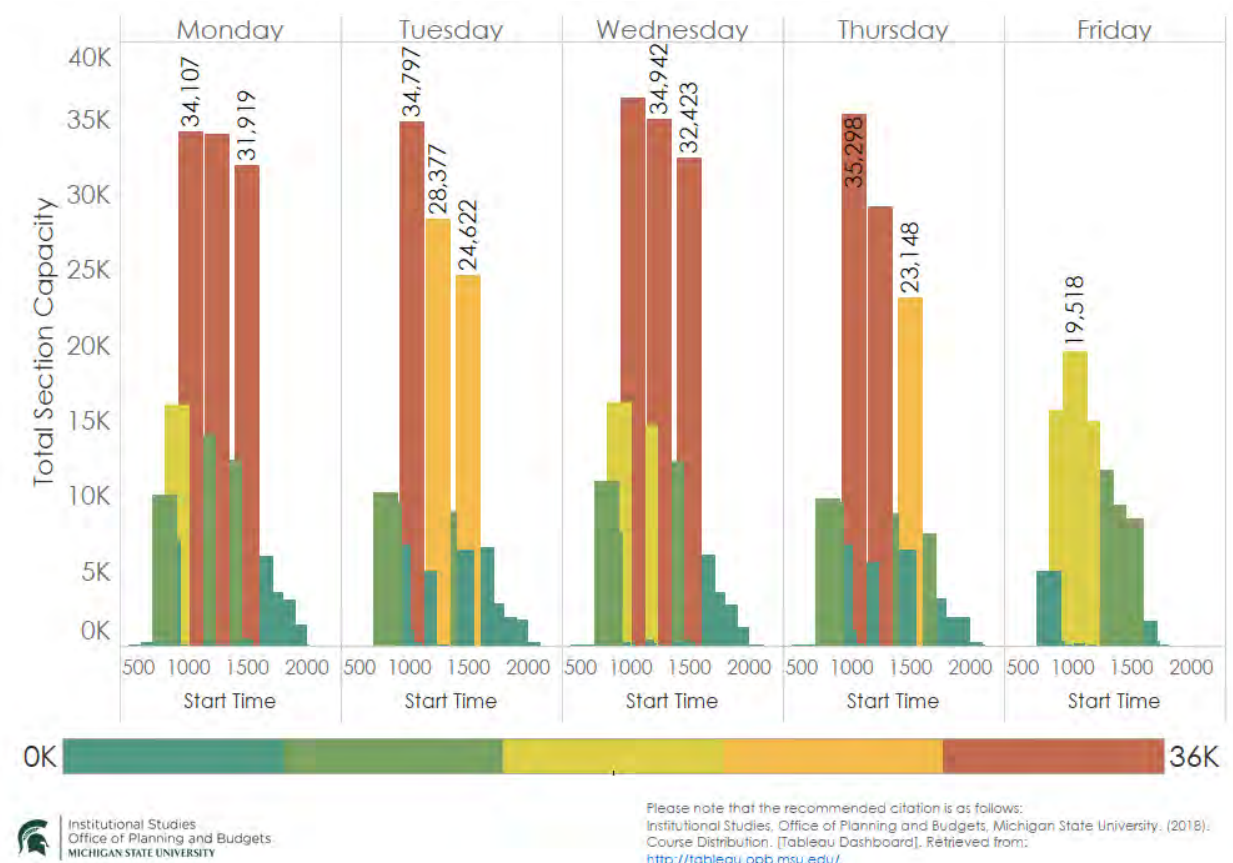


Figure 2: Course distribution by total section capacity, organized by day of the week and starting time (academic year 2017)

The substantial increase in the number of credits in which the 2017 incoming class enrolled and ongoing analytical efforts have revealed some of the structural limitations at MSU that hinder student success. A number of policies, practices, and cultural norms have been identified that impact students' ability to enroll in enough

credits each semester to maintain high levels of credit momentum, and several of these limitations are relevant to mobility issues. Perhaps the most significant of these is rooted in the scheduling of courses, in particular in a congestion of courses offered during a limited number of days of the week and times of the day.

An overwhelmingly large number of MSU's courses are scheduled to start between the hours of 10 a.m. and 3 p.m., especially on Mondays and Wednesdays [Figure 2].

According to analyses by OPB's Institutional Studies, 72 percent of the scheduled seats in fall 2017 were in classes that began within this five-hour window. The 10:20 a.m. starting time is especially busy Mondays through Thursdays; depending on the day, between 18.6 percent and 21.8 percent of the classes offered Mondays through Thursdays start at 10:20 am. While there are apparently sufficient classrooms and faculty resources to schedule courses as is done currently, the relatively intense number of classes that start between these hours can cause problems with both student success efforts and with mobility.

By scheduling a large number of MSU's courses in a relatively short period of time, too many courses meet at the same time and students are unable to fill their schedules. The Go Green, Go 15 effort demonstrated first-year students' willingness to increase their rates of credit momentum when counseled by advisers, but it also revealed the difficulties many of them had in arranging workable schedules, especially in the last several weeks of summer 2017's Academic Orientation Program, when fewer seats were still available in courses.

In order to alleviate these problems, work has been done with the Registrar's Office and OPB's Institutional Studies to find ways to visualize each unit's distribution of courses throughout the day and across the week. It is expected that once units have the capacity to visualize the spread of their courses and the challenges that their scheduling decisions have created for students, a change in the scheduling norms on campus will result. Work is also being done directly with colleges and departments on the scheduling of high-demand courses (especially at the 100- and 200-level) taken by students from across campus to distribute them more broadly throughout the week and across a larger portion of the day.

Current scheduling patterns also create significant mobility issues for everyone on campus. With about 20 percent of classes on Mondays through Thursdays starting at 10:20 a.m. and ending at 11:40 p.m., the campus experiences an overwhelming number of people moving from one location to another on either side of this time slot. It was determined that, on average, students in the fall 2017 semester had 115 minutes between their classes. This means that students are not merely moving from one class to another during this time, but many are likely moving on and off campus, further increasing mobility problems. Distributing classes more broadly throughout the day and week will both improve students' capacity to enroll in larger numbers of classes each semester and decrease congestion at the times that are currently most densely scheduled with classes. It will also make it more likely that a student could schedule courses closer to one another, alleviating the need for them to leave and return to campus.

Thoughtful and coordinated course scheduling represents a significant opportunity to utilize technology, curricular planning, and infrastructure planning in support of improving not only campus mobility planning but also student success. Initial changes to course scheduling suggest that the outcomes associated with these kinds of changes stand to make swift and palpable improvements that could set MSU apart from its peers on multiple fronts.

WAYFINDING "WALKING MAP" SERVICE

Several years ago, the Wayfinding team from MSU's Infrastructure and Planning and Facilities (IPF) contacted the Registrar's Office regarding the potential use of campus maps with walking routes in conjunction with course scheduling. That collaboration resulted in a "walking map" service at the end of summer 2017.

Working together, both units refined and enhanced the Schedule of Courses map to include many features in

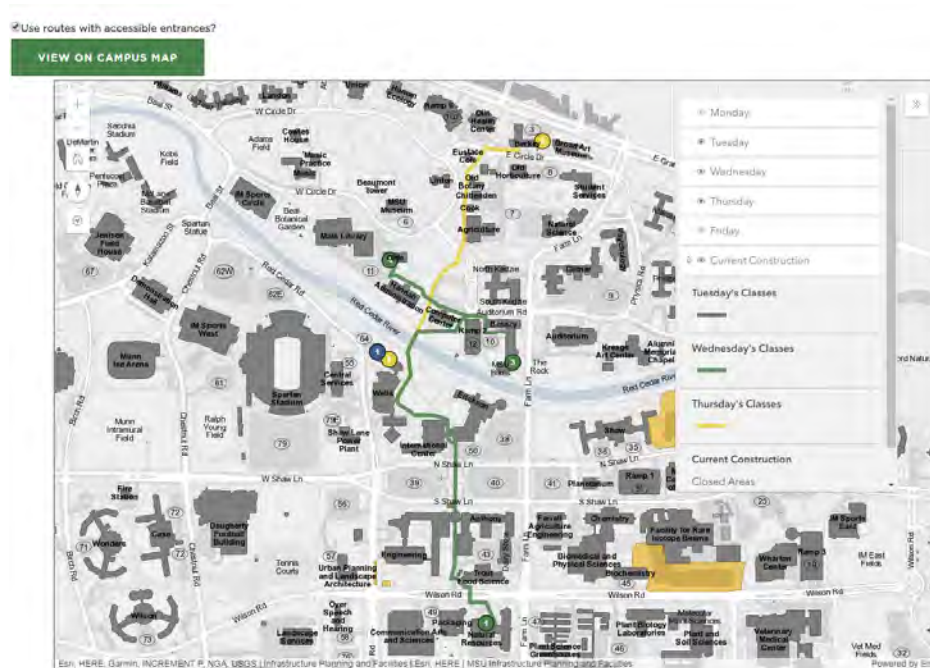
support of student success:

- Display/hide each day's route (useful when routes or meeting locations overlap)
- Identify construction zones
- Calculate accessible route/entrances
- Zoom to building (click on any building or numbered point, then "Zoom to")
- Exact room location and detailed floor plan of buildings (click on numbered point, then "Show floorplan")
- Walking distance and time per day (click on route line)
- Current location (click in upper left corner of map to pinpoint the user's current location)

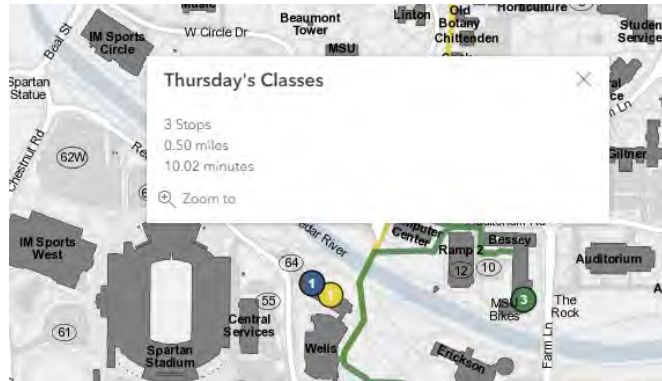
The new features were quietly launched in the Schedule of Courses on August 29, 2017. Within the first two days, more than 5,700 students found and used this new tool more than 9,000 times.

Additional features are now in the works:

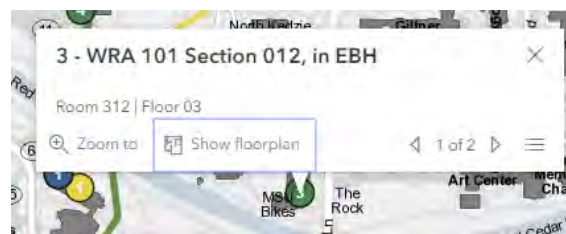
- Students will soon be able to record a non-course entry with a campus location for the map, such as a work commitment.
- Students who live in campus housing will be able to use their housing address as the start and stop point each day.



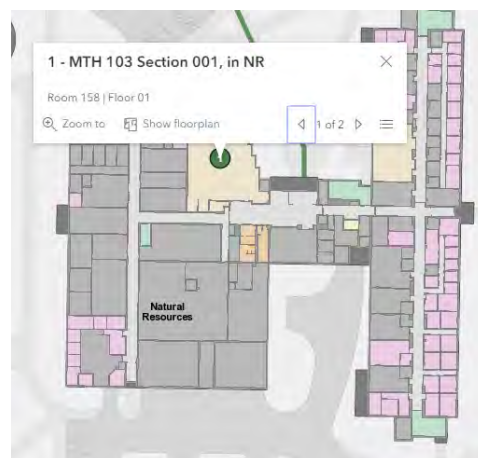
The following is a sample fall 2017 schedule on the map:



Thursday's Classes Map



Single Course/Section Map



Single Course/Section Room in a Building Map

Thoughtful and coordinated use of walking map services represents a prime example of the way in which implementing technology, curricular planning, and infrastructure planning can work in support of improving not only campus mobility planning but also student success.

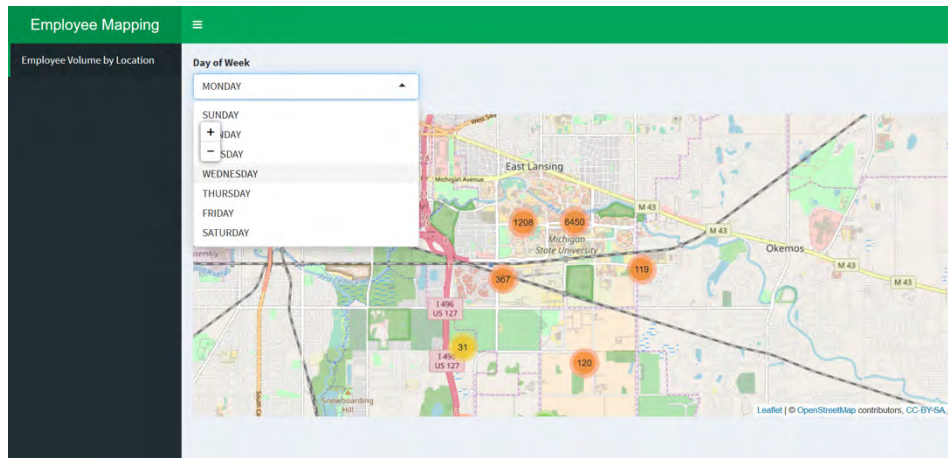
HEAT MAPPING FOR VIDEO CONFERENCING

The IT Services Analytics and Data Solutions team is working to identify strategies to implement the use of heat

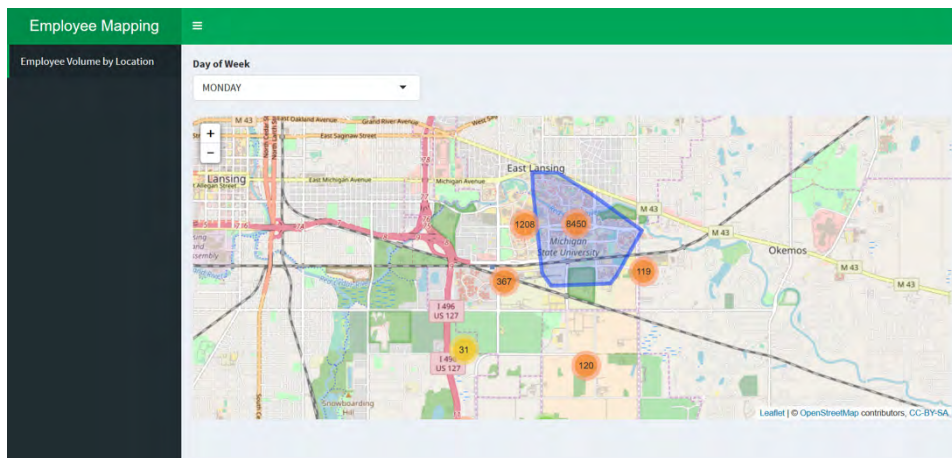
maps for identifying prime video conferencing locations.

Using employee schedules and locations, the volume of expected employees is mapped by day of week and building. The application allows the end user to filter by day of week and drill down to the building level to display expected employee volumes. The current application can include enhancements, such as additional filtering for employee type or department. Future short-term enhancements can include the overlay of conference room locations. Future long-term enhancements may include additional conference room characteristics, such as available technology.

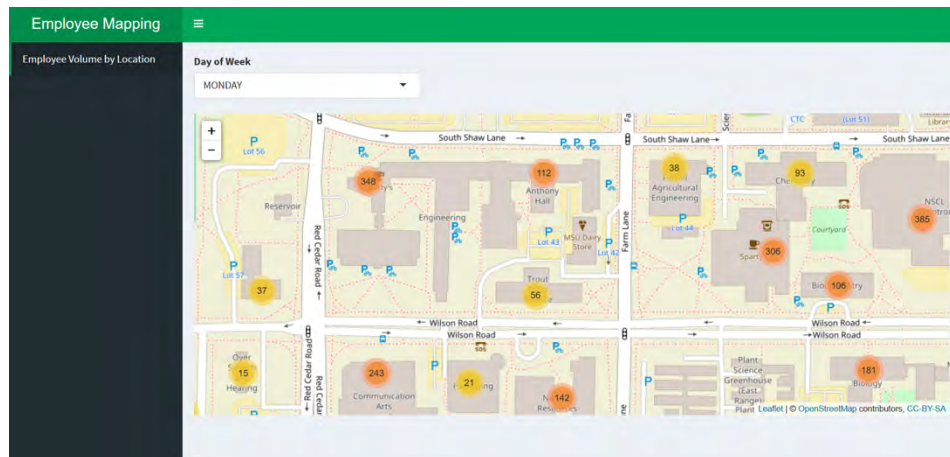
The vision for this tool would be to provide data-driven insight for the campus-wide mobility initiative by reducing the need for travel to and from meetings. Meeting locations could be optimized based on conference room availability and technology components. Meeting “hubs” could be created in convenient, centrally located, highest-volume campus areas.



Map 1



Map 2



Map 3

Thoughtful and coordinated use of heat mapping presents an opportunity to employ technology in ways that will not only improve campus mobility but also improve working conditions and employee satisfaction.

PROPOSED DELIVERABLES

After review and analysis of MSU Mobility Survey data and other existing university data, the following deliverables and changes in MSU business practices are proposed with phased implementation suggested in each instance:

- Increased use of tele-meetings and other electronic methods to connect rather than face-to-face meetings
- Improved use of technology to facilitate off-site work and business processes
- Improved course scheduling, including moving away from peak travel congestion times
- Increased support for and use of flex-time
- Education of supervisors and employees on rationale of and benefits related to flex-time, and ways to make flex-time work within their unit
- Staggered start and stop work times outside of 8 a.m. – 5 p.m. and peak travel times
- Incentives for carpooling, biking, walking, and taking the bus to and from campus

This Phase One overview provides background, context, initial steps taken to identity plans for moving forward, and a suggested outline for next steps. Phase Two will focus on identifying ways to move forward on proposed deliverables, including communications to both internal and external communities. Ways will be identified to communicate relevant services and developments to the appropriate audiences as they become available.

These communications will individually and collectively emphasize, and work toward, encouraging culture changes in support of improving campus mobility. They will also work toward encouraging a shift in thinking, perspectives, and behaviors across the campus community. During each phase, actionable items will involve two-way communications and include the input of creative suggestions. The intent is to communicate that campus mobility planning is more of a living process than a fixed plan, and that the input of all is welcome. Suggestions, comments, or questions regarding campus mobility planning may be sent to mobility@msu.edu, as well as posted at <http://ideas.msu.edu>.

To bring about the changes needed to improve campus mobility, all members of the MSU community will need to critically and creatively examine processes and procedures that have become routinized over the years. All members of the campus community will need to work together to bring about the culture shift required to bring

about substantive changes. New ways to encourage faculty and staff buy-in will be needed, and high-profile offices and committees will need to step up and lead by example.

All available resources across campus—such as the Office of the Executive Vice President for Administrative Services, Hub for Innovation in Learning and Technology, the Office of the Associate Provost for Undergraduate Education, IT Services, Academic Services, Enrollment Management, and the WorkLife Office—will need to be engaged in a coordinated fashion to explore possible solutions. The continued use of data and cross-unit collaboration will be central to the ongoing success of MSU’s Mobility Plan. Those already engaged will need to remain engaged, and those not yet engaged will need to be brought into planning efforts.

The answers and solutions to improved campus mobility lie in the creativity and innovation of MSU faculty, staff, and students in imagining and then implementing a broad range of culture changes across campus—changes that will not only improve mobility but also student success and employee work–life balance. In many cases, a single change in practice in one area will result in positive outcomes across other areas of campus as well.

With each phase of implementation, MSU’s Mobility Plan will enhance mobility and convenience, improve the on-campus experiences of members of the MSU community and those who visit campus, influence behavior and find new ways to optimize mobility, and position MSU as a recognized mobility leader. It will also increase opportunities for student success; provide a high-quality educational and work environment; increase safety; promote positive on-campus experiences for students, faculty, staff, and visitors; encourage environmentally sound practices, and support cutting-edge research.

INFRASTRUCTURE

MSU INFRASTRUCTURE COMMITTEE

Allen, Nancy (Office of the University Physician)
Carpenter, Jeffrey (IT Services Infrastructure Support)
Cooper, Lauren (Forestry)
Erhardt, Ann (IPF Strategic Initiatives)
Gardner, Scott (Engineering and Architectural Services)
Gates, Tim (Civil and Environmental Engineering)
Ghamami, Mehrnaz (Civil and Environmental Engineering)
Maher, Nathan (University Services University Stores)
O'Donnell, Stephanie (Department of Police and Public Safety)
Potter, Tim (MSU Bikes)
Rosick, Edward (Healthy Campus Initiative Family and Community Medicine)
Troost, Steve (IPF Administration)
Voss, Nicholas (IT Services Analytics and Data Solutions)
Weinfeld, Arnold (Institute for Public Policy and Social Research)
Wilson, Mark (School of Planning, Design and Construction-CSS)
Witter, Scott G., sub-committee chair (Administrative Services)
Zockaie, Ali (Civil and Environmental Engineering)

OVERVIEW

Michigan State University has one of the largest contiguous campuses among U.S. universities with the population of a medium-sized city. It encompasses 5,200 acres—2,100 acres north of Mt. Hope Road containing most of the campus's infrastructure and 3,100 acres south of Mt. Hope Road primarily devoted to research farms. There are 57.44 miles of roads, 120.81 miles of sidewalks, 19.51 miles of bike lanes, more than 26,000 parking places, and disability access sites to more than 500 buildings. All of this must be maintained and managed to protect the safety of everyone on campus.

During fall and spring semesters of 2016, 17,500 students lived on campus, 32,500 students commuted to classes, 12,500 employees worked on campus, 177,379 deliveries were made to University Services, and hundreds of thousands of visitors came to campus, in addition to the construction company crews and others who were on campus daily. At the same time, the Capital Area Transportation Authority (CATA) bus system utilized campus roads to provide more than a million rides per semester. Additionally, many individuals take part in athletic and academic camps all summer long.

Year-round mobility strategies are required to provide a stable and predictable suite of options in this infrastructure environment. While MSU does a very good job of managing its infrastructure, there are major opportunities to focus this work as part of a campus-wide sustainable mobility plan. This report focuses on MSU's current infrastructure and on ways to model and integrate its management to make campus more sustainable in the future.

In order to plan and manage the campus infrastructure, it was first necessary to understand the current academic and planning imperatives and how they fit into the MSU Bolder by Design strategic initiatives that guide the university. Based on this assessment, the next step was to understand how the current infrastructure is used and

managed. Immediately obvious was that many individuals and units on campus manage and plan different portions of MSU's infrastructure and that new opportunities and mandates often alter long-range planning.

Much of the infrastructure work focuses on the conditions of roads, parking lots, and sidewalks with little in-depth research on who uses the infrastructure daily. Factors such as when and where classes are taught, visitors are on campus, and deliveries are made, in addition to what employees and students feel their needs are, don't seem to be consistently factored into the decision-making process in a holistic and long-term manner. MSU has very capable and talented employees managing and planning for components of MSU's infrastructure; however, they are spread across several units under several different administrative structures with mixed priorities. What is more, these units are not fully integrated with the units that manage students, employees, visitors, and training activities across campus.

A brief review of how several similar universities and some dissimilar universities manage their infrastructure revealed that many operate just as MSU does and function well. Most don't integrate employees and students into the actual planning process on a consistent basis, which is an issue if a sustainable mobility system is the preferred result of this work. Some highlights of that review:

- North Carolina State University seeks to improve its bus service and improve traffic patterns in a cost-effective manner. During a 2012 campus mobility planning exercise, two small public charrettes were held with campus employees and residents.
- Ohio State University is promoting one-stop parking for employees to reduce the congestion on campus and has sold its parking lots and their management to a private company. Subsequently, there have been at least four years of 7 percent increases in parking costs.
- Pennsylvania State University has sought to be greener in its fleet vehicles by switching to biofuels and encouraging walking, biking, and public transportation. The university has sought to provide low-cost bus service for students both on and off campus to help meet these goals.
- The University of Illinois is considerably more holistic in its approach than most other universities according to its 2009 mobility plan. It has a preferred investment plan for campus that creates green corridors based on needs in a sustainable framework for campus and the surrounding community.

The Sustainable Urban Mobility Planning Initiative being promoted to all cities in the European Economic Union is truly the most holistic and sustainable approach and is the preferred approach if MSU wants a sustainable mobility system on and off campus.

To better consider MSU's readiness to follow a sustainable planning initiative for its infrastructure, many ongoing and proposed infrastructure-related projects were reviewed. Also reviewed was the Healthy MSU Campus Initiative as it relates to infrastructure planning, as well as remote teaching and meeting robotic options. Many recommendations affect MSU's sidewalks, green areas and roads. MSU Sustainability also provided input regarding its current programs, future visions, and proposals for measuring the impact of these programs on campus sustainability.

Most of MSU's current infrastructure work focuses on building, maintenance, and related technology. While this works, it is not as efficient and cost-effective as a more holistic, sustainable system. To attain a sustainable management system, MSU needs to add a significant social component to its planning efforts. Several charrettes and a survey at the beginning of the process are not enough. What is needed is consistent interaction with MSU's employees and students, as well as with technical analysts, research faculty, and decision makers. This includes creating a clear relationship of how to incorporate the ALERT model—a planning-practice process for knowledge-based urban and regional development—as a sustainable operating approach during the development and implementation stages of new technologies. There needs to be a clear, long-term focus on responsiveness to social needs now and into the future throughout the planning and management of MSU's infrastructure.

NEEDS AND STEPS TO ADDRESS THEM

MSU needs a holistic, integrated, sustainable mobility plan that guides all components of infrastructure management on campus. The plan needs to focus on campus as a place where employees, students, guests, and visitors come to work, learn, live, visit, and play. Infrastructure management is an integral part of MSU's overall mobility and is a critical part of what makes MSU a unique, functioning, and exciting place.

There is a clear need to build on what MSU is doing in a way that will make it more responsive to social needs and pending technology changes, as well as more sustainable. Three steps are needed for managing MSU's infrastructure in a holistic and sustainable manner. The steps are intended to be nested into one another over time, allowing MSU to transition into the changes and as budgets permit:

- The first addresses the primary, near-term infrastructure and planning needs, including changes in day-to-day management.
- The second focuses on more extensive social interactions to better understand not only employee and student needs and wants but also the incentives MSU must implement to encourage these individuals to accept and use recommendations that would make the campus infrastructure more sustainable and safer.
- The third focuses on how MSU can better plan for and manage its infrastructure within the concepts of a sustainable mobility planning framework by creating and using a geographical information system (GIS) modeling approach that will link all units on campus from planning to implementation with regard to issues such as class locations and times, traffic safety options, and prioritization and budgeting of maintenance and new building construction.

The system provides "what if" modeling options based on a series of relational data created every year from across MSU. This system will provide all MSU decision makers with access to the same data, analyses, and alternatives prior to making final decisions. For example, prior to construction of a new teaching facility, it is critical to know such things as who will teach in the building, where the students will come from and go after classes, where faculty will come from to teach, location of utilities, location of sidewalks and roads, and brownfield concerns.

If MSU decides not to adopt a sustainable mobility planning approach, the near-term recommendations should to be addressed in the next three years.

MSU's planning relationships with East Lansing, Lansing, and Meridian Township are not covered in this report but are critical to the concept of a sustainable mobility plan and should be addressed. MSU is already fully engaged in this work through its Office of the Vice President for Government and External Relations. This work can be integrated into the modeling process described in the third step of this chapter.

STEP 1

This step addresses the primary, near-term infrastructure and planning needs, including changes in day-to-day management.

GOALS

The primary goals of this step are:

- Prioritize car, bike, and pedestrian safety.

- Start development of a sustainable mobility plan.
- Implement a new one-stop parking system using existing infrastructure. Practices such as tiered parking prices and rebates for days not used should be considered.

This step represents the least change to planning and managing MSU's infrastructure. MSU has excellent employees dealing with creating and maintaining its infrastructure through a system that has worked for many years and represents the norm at most major U.S. universities. Currently, each unit engaged in creating new infrastructure and maintaining it submits plans and needs assessments for approval at the unit level. Approval from two standing committees is then needed before the plan is incorporated, perhaps with modification, into the Office of Planning Budgets' annual budget request presentation to the president and Board of Trustees. The process is guided by MSU's master and land use plans, but is flexible enough to accommodate new opportunities and needs.

NEAR-TERM NEEDS

MSU has strategic and land use plans that guide all infrastructure changes on campus. A centrally organized evaluation of the impact of these plans on MSU's campus, employees, and students should be conducted annually to clearly document trends and make corrections as needed to ensure the desired effect.

Infrastructure is a core part of MSU mobility and needs to be central to any sustainable mobility planning effort on campus. Ideally this would be led, developed, and managed under the Office of the Vice President for Administrative Services. All the units that manage MSU's infrastructure already report to this office except the MSU Police Department, and it would be a logical data hub for analysis and impact reviews.

There should be a standing committee of the unit heads that create the sustainable mobility plan. They should meet monthly to assess the progress of the plan's implementation and when necessary to make course corrections. Relevant data, GIS modeling, and planning documents related to MSU's infrastructure should be accessible and web links maintained through Administrative Services office for core team members. There needs to be a single "go to" place for all relevant data so these resources can then be linked to all other units that use and impact infrastructure. This is a need that should be addressed within the next year.

MANAGING DATA AND INFORMATION

Easy access to current and future infrastructure data, reports, modeling software, maps, and figures is essential to successful planning and implementation. It is important to ensure that university executives, faculty researchers, specialists, the MSU community at large, and outside partners alike can easily access non-sensitive infrastructure data. Effective short-term access and report dissemination is vital to maintain the current mobility momentum. New analysis and modeling techniques will emerge from these interactions.

MSU Information Technology (IT) staff, including leaders charged with developing next-generation academic support technology, recommend using tools from the newly launched "Spartan365" online collaboration suite in MSU's infrastructure/mobility effort. Establishing a Spartan365 SharePoint online presence provides a living repository and allows for granular security access as needed through Spartan365 OneDrive cloud data storage. This process meets MSU's institutional data storage standards and, more important, is part of the evolving and IT-supported collaboration tool roadmap.

Taking advantage of existing tools, especially ones that are strongly supported by IT, can ensure uninterrupted access to the vital data collected during infrastructure planning, implementation, and evaluation or through related efforts for all interested parties in the future.

At least one analyst should be housed in the Administration Building to ensure that the GIS modeling needs can be met on a day-to-day basis. The GIS modeling effort is only as good as the information that is in the system.

IMMEDIATE NEEDS

There are significant traffic congestion and safety concerns that need to be addressed. Traffic flow of pedestrians, bikes, mopeds, cars, delivery trucks, and buses described in the full Infrastructure Report 2018 poses significant issues from 10 a.m. to 2 p.m. —the peak infrastructure use time of the day. The same is true for the major entry and exit roads for 12,500 employees and 35,000 students, as well as construction workers, visitors, and others. See the end of this chapter for specific recommendations.

While there are more than 26,000 parking spots on campus, parking remains an issue. Employees often drive to meetings despite options that could include walking, biking, web-based meetings, and reliably scheduled buses. Currently, there are no incentives to dissuade employees from driving and trying to park in the lot closest to their destination. Depending on location, some lots are already full, which causes employees to drive around looking for a parking spot multiple times during the day.

One potential way to limit driving on campus is to implement one-stop parking, where every employee has an assigned space within 15 minutes walking distance of where they work. This makes getting to work easier and timelier. If employees can have 90 percent of their work within that distance, there is little need to move their car during the day until they need to leave campus.

While every employee at MSU has a free ride pass on the CATA system, few take advantage of this service. If schedules can be held to no more than five minutes between buses on the major north/south and east/west transportation arteries and employees are willing to use the buses for on-campus travel, traffic congestion can be significantly reduced during the day. Combined with scheduling classes to avoid mass movement at peak travel times, this should reduce car, bike, and pedestrian accidents.

Students could be restricted from parking between the railroad tracks to the south and Grand River Avenue to the north of main campus, except for loading and unloading possessions at their residence halls to further reduce congestion. Nonemployee-based parking could be limited or eliminated in this area to further help reduce congestion. Class times and locations could be evaluated and changed to reduce peak flows. These are near-term issues that need to be addressed on a priority basis over the next one to three years. The priorities would be set during implementation of the sustainable mobility plan.

STEP 2

This step focuses on more extensive social interactions to better understand not only employee and student needs and wants but also the incentives MSU must implement to encourage these individuals to accept and use recommendations that would make the campus infrastructure more sustainable and safer.

GOALS

The primary goals of this step are:

- Prioritize incentives that will encourage employees and students to adopt changes in MSU's infrastructure management.
- Continue development and implementation of a sustainable mobility plan.

CREATING INCENTIVES FOR CHANGE

Getting students and employees to adopt changes that make MSU a safer and more sustainable place to work, live, learn, and play will not be easy. Most of these stakeholder groups do not tend to embrace change and question why they should have to do things differently. Most organizations simply implement policy and plans without understanding how their employees feel about making changes. This results in turmoil with people often not doing what the new innovations try to achieve. Getting this information is challenging and requires involvement of the skilled research and outreach specialists already on the MSU faculty.

Making innovation change less daunting requires knowing what people need and want from their work, living, and learning environments. These stakeholders need to understand why change is necessary, such as for safety, economic, sustainability, or health reasons. This requires being in contact with them through user groups and surveys throughout the planning and implementation process. In some instances, economic and quality-of-life incentives are identified that most students and employees hold in common. Utilizing desired incentives to encourage adoption of innovations makes needed change much easier to achieve. If done well, this process will expand trust and support among the stakeholders.

There are few incentives for change in the current parking permit structure for MSU employees. The current system does not allow for much flexibility for employees when it comes to payment amounts and locations on campus. Financial incentives need to be explored that encourage alternative modes of transportation and parking infrastructure. Currently, once an employee purchases a multiple-semester permit, there is no incentive to try a bus, bike, or carpool alternative. They can park in any available non-permit space and often spend significant amounts of time looking for a space. Often this movement takes place from 10 a.m. to 2 p.m. when thousands of students are moving to and from class.

Alternatives to this pattern might include:

- Create a “Commuter Club” like at Indiana University Bloomington that makes it possible for employees to return their parking permit and receive the following benefits if they commit not to renew the permit:
 - Free access for campus and city buses
 - Option to purchase a pack of one-day parking passes for use when parking is more essential
 - Free emergency rides home
 - Reimburse some of the monthly parking fee (for example, 25 percent refund for parking less than 75 percent of the days).
 - Provide free parking passes for use on days when parking is more essential by using bike, bus, or carpool commuting.
- Have zip cars available on campus that can be driven to meetings during bad weather or when last-minute needs arise.

Clearly communicating employee options is also critical in adoption and maintenance of planning and policy. The following issues need to be addressed in the employee parking permit section of the MSU Police Department website:

- The site is not accessibility-aligned, has low readability, and is not generally user-friendly.
- Employee 89 permit should be clearly highlighted as an option to reduce parking issues and traffic.
- Bus routes specific to MSU should be linked directly to the MSU web page, rather than to the CATA site where it is difficult to find a bus route without knowing route numbers.

Further, with regard to buses, the most requested buses from the parking lot at Farm Lane and Mt. Hope Road only goes as far as Shaw Hall, which doesn’t help employees who work farther north on campus. Each employee “neighborhood” should be linked directly to a commuter lot with a bus every 10 minutes during business hours.

The contract with CATA should address the following possibilities:

- Free rides on all CATA buses for students, faculty, and staff both on and off campus (as at Pennsylvania State University and the University of Michigan through the Ann Arbor Area Transportation)
- Free rides to and from campus for employees
- Free rides for employees and off-campus students to a “Commuter Club” (as at Pennsylvania State University)
- A series of reasonable bus options for the larger student and employee neighborhoods in East Lansing, Lansing, Okemos, and Haslett
- Primary commuter lot buses that cycle frequently from surrounding cities to key neighborhoods on campus

MSU needs to evaluate how to accomplish the following:

- Reduced reliance on parking permits as revenue for buses
- Increased valuation of health and emissions reductions
- Multimodal approach to addressing both parking and the need to encourage and nurture the desire to have alternative transportation both to and from campus and across campus
- Clear communication and marketing regarding bike and scooter options
- Reward incentives such as free ice cream, coffee or event parking passes to encourage employee participation in new parking options

This step seeks to reduce congestion and help provide a safer campus for employees and students by engaging them more in walking, biking, bus riding, carpooling, web conferencing, and the future use of autonomous automobiles for travel on campus. The literature shows that older employees are the most reluctant to adopt innovations and younger are the most open. This option needs two- to three-year assessments to determine the impact of these innovations on MSU’s sustainable campus needs.

STEP 3

This step focuses on how MSU can better plan for and manage its infrastructure within the concepts of a sustainable mobility planning framework by creating and using a GIS modeling approach that will link all units on campus from planning to implementation with regard to issues such as class locations and times, traffic safety options, and prioritization and budgeting of maintenance and new building construction.

By utilizing GIS with a series of relational databases already available at MSU, it is possible to precisely model a wider number of planning and implementation options that can lead to a more sustainable campus. This step is enhanced by implementation of the first two steps but can and should be implemented as early as possible in the planning and implementation process.

The primary goals of this step are:

- Develop a modeling framework that will lead to a sustainable mobility plan.
- Create a modeling approach that can be jointly and simultaneously used by all units working with MSU’s infrastructure from planning to budgeting to construction.
- Allow availability of data and GIS-based modeling of new building locations, infrastructure maintenance, budgeting, accident prevention, health enhancement, and class scheduling to all relevant units.
- Provide more nuanced solutions by age, disability, and unique job requirements.
- Provide multiple precise parking options that are equitable and economically viable.

GIS MODELING AND MANAGEMENT SYSTEM

It is necessary to base infrastructure needs, options, and priorities on data that can be easily used by the decision makers in multiple levels at MSU. GIS and the collection of relational data are the cornerstones of this process. GIS is a computer-based software system that allows the user to overlay multiple layers of information and interrelate them with relational databases. It allows planners and managers to visualize, analyze, and interpret data for one or more geographic areas/regions to see and understand relationships and patterns that currently exist or could exist between the physical environment and land use.

Relational databases contain such information as employee locations in relation to parking and work and student class schedules and locations across campus. Combining this data with GIS makes it possible to cross-tabulate the data with unit employment to determine patterns and needs. Use of this modeling process for sustainable parking solutions and tracking student movement by college and time of day is illustrated below.

EMPLOYEE PARKING MODELING EXAMPLE

Existing relational databases were modified to make it possible to determine how many employees of various designations and ranks are in each building on campus. These were combined with GIS data sets that show the location of each building and the employee parking lots surrounding each building.

The question asked was: Could employees be assigned a parking space within a reasonable walking distance of their primary worksite so that they did not have to search for parking multiple times a day? The next step was to run iterations of the model to allow determination of how many of the employees could park within 5, 10, and 15 minutes of their primary worksite.

The first run of the model shows the distance between each building and employee parking lots within a five-minute walking distance. The numbers in the small squares located on some of the buildings represent how many employees of all designations could not park within this radius currently.

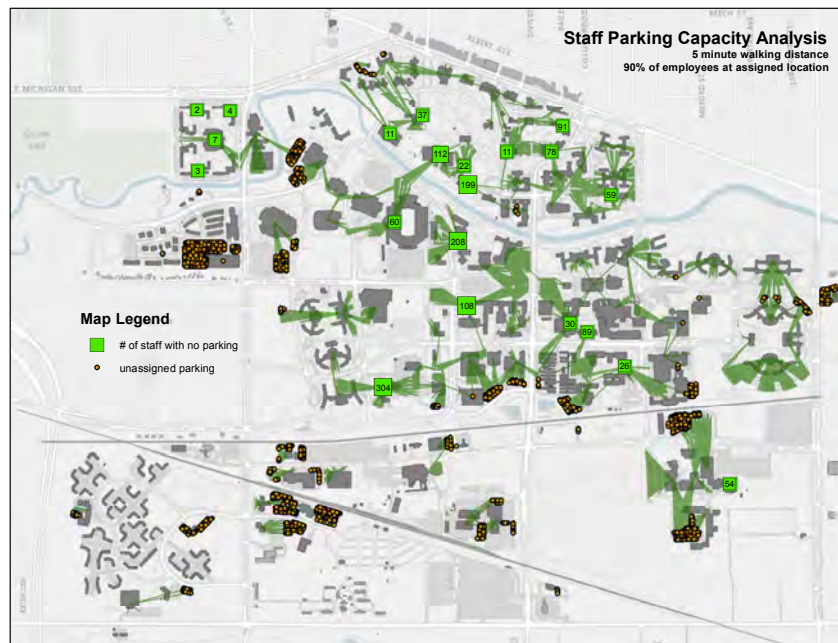


Figure 3: Five-minute parking options

This map and data can be used to make sure that employees with health or physical disabilities can be assigned a

parking space that is closest to their work. Following these assignments, others requiring proximity parking can be accommodated. The remaining parking options can be assigned by some other system, such as a lottery or incremental cost.

The next map shows what happens if a 10-minute walking proximity is considered.

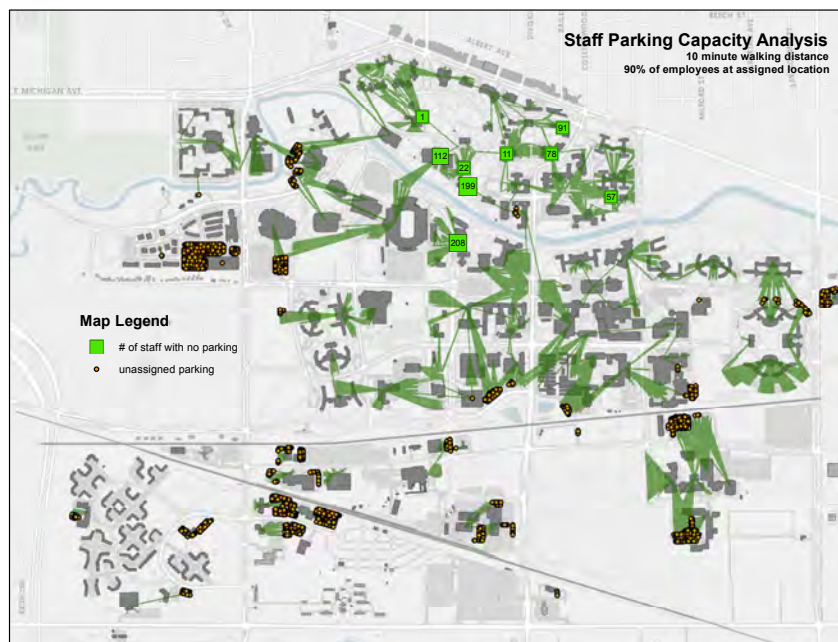


Figure 4: Ten-minute parking options

The number of buildings with employees who cannot be assigned a parking space within a 10-minute walk to their worksite goes down significantly from the five-minute model. Again, health, physical issues, and other needs can be accommodated, and the need for additional parking options can be determined. This could include new parking ramps located where they are needed and/or incentives, such as lower parking costs for employees willing to walk, bike, or bus to and from available parking at a greater distance.

The following map represents what happens with assignment of parking within a 15-minute walking distance of the worksite. In this scenario, only 195 employees in four buildings cannot be assigned a parking space within a 15-minute walk of their worksite. Only about 8,000 of MSU's 12,500 employees purchase parking permits. Rerunning the model after deleting the non-purchasers would reduce the number of employees without assigned parking options even further. It could be possible to make all the parking assignments without new parking structures. If not, it would be possible to utilize a series of the incentives as suggested in step two to achieve employee-driven solutions.

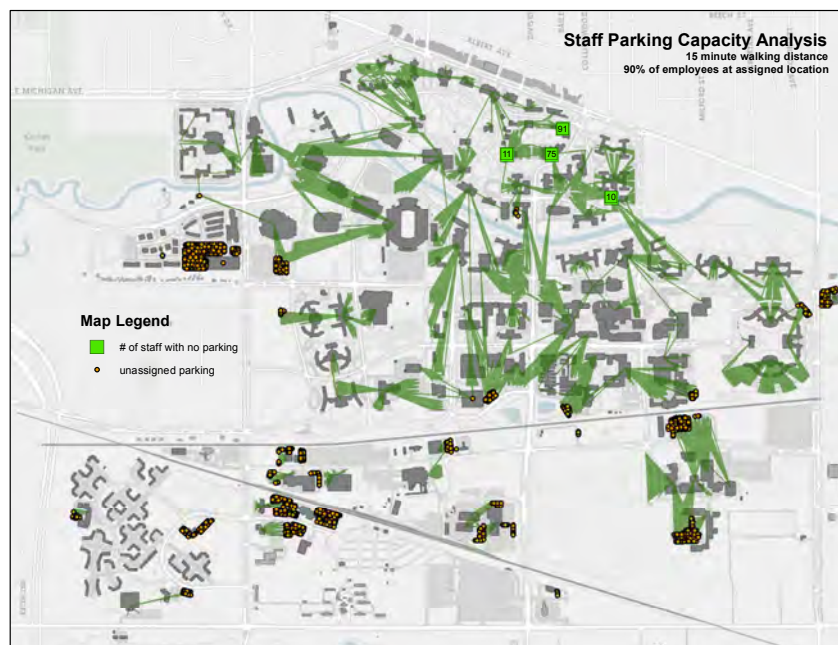


Figure 5: Fifteen-minute campus parking options

This process allows MSU to plan based on the exact number of employees with parking needs and the specific location of each employee to reduce the number of trips that involve searching for parking dramatically. Fewer trips would mean less congestion and should help reduce car-related accidents.

STUDENT MOVEMENT EXAMPLE

Another use of the model was to track student movement from class to class throughout the academic week. Determining how many students leave the buildings at what times makes it possible to identify “pinch points” on campus. The information can be used to alter class scheduling to help manage student flow over the entire week to reduce congestion and problem areas, such as North Shaw Lane, South Shaw Lane, and Farm Lane south of the Red Cedar River.

While the College of Social Science (CSS) and the College of Engineering (CE) had a similar number of student majors during fall 2017—6,272 and 6,342, respectively—there were significant differences in how many buildings that the students were in during an academic day. CSS has more departments located in more buildings.

The following example shows the number of students scheduled in classrooms within a five-minute walk of CE and CSS classroom buildings during two one-hour periods on Monday, November 6, 2017: At 10 a.m., 5,302 students were scheduled in classrooms within five minutes of CE classroom buildings. At 11 a.m., that number jumped to 8,463 students. For SSC classroom buildings, the numbers were 6,909 at 10 a.m. and 12,732 at 11 a.m. These numbers reflect where and when the students are supposed to be in class in the buildings indicated, but obviously students can miss these classes for a wide variety of reasons. However, this remains the most accurate hour-by-hour information available regarding student movement.

This information can be used to identify pinch points on MSU’s sidewalks and roads and allows evaluation of where and when classes can be taught to help reduce these points. It will also be possible to cross-tabulate these points with accident locations and times to evaluate the impact of rescheduling classes to reduce points related to accident.

SPECIFIC SHORT- AND LONG-TERM CAMPUS MOBILITY AND SAFETY RECOMMENDATIONS

This series of recommendations is based on consideration of campus traffic and safety issues, along with other factors, and is organized into near-term and long-term categories.

NEAR-TERM TRAFFIC AND SAFETY ISSUES

- Continue to implement pay-by-plate parking throughout campus.
- Continue to move away from surface parking to ramp parking.
- Consider moving to a dedicated parking space model for campus employees, which would involve assigning a specific parking area near each employee's primary worksite to help reduce intraday campus trips. Implementation will require collection of time/distance data from each building or work area to the most logical parking areas.
- Consider financially incentivizing parking in Lot 89 (commuter lot) for employees, which would include providing regular dedicated shuttle service to and from central campus. Incentives may be as extreme as providing free parking for these permit holders. Similar parking incentives for fringe parking areas have been found to be successful on other campuses, including the University of Michigan-Ann Arbor.
- Continue to financially disincentive employee parking in the central core of campus, possibly including designating central campus parking for visitors only.
- Continue to improve bicycle and pedestrian mobility on campus, including the addition of bicycle lanes, especially buffered bicycle lanes and off-roadway facilities, and enhancements to pedestrian crossing areas, including expanded use of the in-crosswalk "yield to pedestrian" signs. Further investigation is needed into the occurrence of bicycle crashes on Farm Lane in the central campus area, with effective crash reduction countermeasures implemented.
- Continue efforts to lower traffic speeds through central campus, including use of speed display signs, traffic-calming countermeasures, and speed enforcement. Special signal timing strategies may also be implemented to prevent continuous traffic progression through central campus, particularly on Shaw Lane, Farm Lane, and Wilson Road.
- Continue and consider expansion of the University Services' one-stop delivery initiative, which requires routing of delivery vehicles through Central Receiving. This will allow for the control of deliveries, reducing campus and dock congestion and mitigating related risks while enhancing campus safety and the pedestrian experience.
- Consider a managed approach with institutional partners tasked with identifying and reducing redundant delivery and pickup activities, such as Residence Education and Housing Services-Food Stores routing nonresidential deliveries through Central Receiving.
- Modernize traffic signal equipment to allow for better control of campus traffic and to accommodate connected and autonomous vehicles.
- Expand efforts to regularly collect bicycle and pedestrian traffic flow data in addition to regular vehicular traffic counts. This includes exploring options that would allow for such data collection to be automated using equipment temporarily or permanently installed at strategic locations across campus, particularly at entry and exit points.
- Consolidate campus spatial data sources related to mobility and infrastructure into a central repository to streamline mapping and analysis in support of campus planning activities.

LONG-TERM TRAFFIC AND SAFETY ISSUES

- Continue to place new parking ramps near the main entry and exit points to campus. Ramps 5, 6, and 7 are good examples of well-sited ramps with respect to placement of parking areas near the campus entry points from the major roadways. This would coincide with removal and decommissioning of parking areas near the central part of campus.
- Consider establishing institutional policy based on the identification of core competencies and ultimate responsibility for the movement and delivery of goods.

Traffic capacity reductions should be considered on Shaw Lane between Red Cedar Road and Farm Lane. This may include removal of one traffic lane on both the north and south sides of Shaw, closure of either the north or south side of Shaw to normal traffic with an optional bus lane maintained, or outright removal of both the north and south sides of Shaw. This would greatly reduce east/west traffic in the central campus area and would have a general calming effect on traffic.

This alternative will likely increase traffic volumes on Wilson Road and Farm Lane. Remedial measures may be necessary to address consequential safety and operational issues that may result, particularly on Farm Lane, which already possesses the highest occurrence of bicycle crashes on campus. Access to affected parking lots would need to be reconfigured to either Red Cedar Road or Farm Lane. Alternatively, these parking lots could eventually be removed and repurposed. Infrastructure maintenance planning and work would remain as it is now in this option.

RECOMMENDATIONS FOR CAMPUS TRAFFIC MANAGEMENT

These recommendations seek to resolve pedestrian flow conflict with cars at class transition periods, smoothen car flow during the class transition periods (a.m. peak and p.m. peak), propose and test parking management strategies, and promote public or shared modes of transportation. To achieve these objectives, a comprehensive multimodal traffic model is needed that can estimate travel times and congestion distribution over the entire campus.

The traffic model provides travel time information for different trips on campus or commuter trips to and from campus. The sensitivity of the multimodal traffic model to different strategies enables assessment of the impact on congestion distribution over the campus. Developing a multimodal traffic model that can simulate all on-campus trips requires a comprehensive survey study from faculty, staff, and students. Availability of data affects the accuracy of the traffic model.

Two main categories of data—supply and demand—are required to develop the traffic model. The supply information includes roadway and intersection characteristics, parking lot locations and capacities/utilization, and public transportation routes and schedules. This information is available or can be easily collected on campus or from neighboring cities. However, a comprehensive travel survey is required to collect demand information. This survey provides information on origin (building name for the campus and closest intersection for others), destination (building name for the campus and closest intersection for others), departure time (15-minute time window), and travel mode for each trip of the survey participant in addition to general socioeconomic information, such as occupation, age, and gender.

Here are some possible solutions that can be tested through the multimodal traffic model.

Traffic Control

- Implement time-dependent signal timing at class transition periods.
- Use phases just for pedestrian crossing in all approaches at class-transition periods.
- Identify pedestrian volume to allocate the extra exclusive phase in signal timing.

Parking

- Provide information on visitor and open parking availability.
- Enable reservation of visitor parking spots online.
- Institute demand and time-dependent parking pricing.

Public/shared Transportation

- Provide smart public transit using autonomous electric vehicles.
- Provide a preassigned ride-sharing service, such as a carpool or vanpool, using regular or autonomous electric vehicles.
- Establish an automated system including shared modes of bikes, pedicels, and scooter-style electric bicycles.

The suggested steps to achieve these solutions are listed below as near-term and long-term strategies.

NEAR-TERM STRATEGIES

Collect data required for the traffic simulation and analyses:

- Comprehensive travel survey (demand generation zones and attraction zones)
 - Campus road network (roads, intersections, and traffic control devices)
 - Parking data (number of parking lots, parking spots, and permits categorized by type)
 - Residential halls (number of residents and their major)
 - Transit (routes, schedule, and fleet)
 - Building configuration (location, area, number of class rooms, number of students faculty, and staff)
 - Class information (location, schedule, and number of students)
- Build campus network in a GIS-based software such as Trans CAD.
- Simulate traffic (motorized and non-motorized) on campus considering class schedules and locations, staff working hours and travel origin and destination, and stochastic faculty schedules.
- Find the traffic-related issues on campus, analyze the reason for each issue, and propose solution strategies.
- Long-term Strategies
 - Test strategies to increase mobility and safety on campus and report the costs and benefits of each strategy.
 - Implement the optimum strategies and continue data collection to assure the effectiveness of each strategy.
 - Monitor demand (repeating travel surveys every three to five years) and supply changes throughout the campus to update the multimodal traffic model of campus.

This series of recommendations is based on consideration of campus traffic and safety issues, along with other factors, and is organized into near-term and long-term categories.

CENTRAL RECEIVING AND DISTRIBUTION

CURRENT CONDITIONS

MSU's overall infrastructure is used in many ways to facilitate its needs. University Services manages the supply chain for MSU, incorporating the institutional objectives of global engagement, Bolder by Design, 2020 Vision, cost containment, and environmental stewardship. Tasked with providing an uninterrupted flow of materials in support of MSU's mission, Central Receiving strives to continually improve processes related to campus safety and security, compliance, and consolidation of redundant deliveries. From fiscal year 2014 through 2016, MSU was averaging more 176,000 deliveries annually.

Near-term Recommendations

- Continue efforts to expand the one-stop initiative.
- Research and deploy GPS fleet management system for institutional fleet.
- Load and layer primary routing into institutional GIS systems for delivery route planning, optimization, and daily operations planning.
- Investigate opportunities to reduce redundant deliveries through comingling and routing.
- Limit delivery times on campus to before 10 am and after 3 pm.

Long-term Recommendations

- Engage GIS platforms and data to optimize delivery routes and daily operating plans.
- Engage Purchasing, College of Business (Department of Supply Chain Management), College of Engineering, carriers, and other constituents to design a supply chain model based on managed inbound flows prior to campus arrival.
- Partner with College of Engineering and College of Business (Department of Supply Chain Management) to use GIS to develop a test-bed for autonomous technology and delivery vehicles.
- Engage institutional leadership and define policy for core processes and ultimate responsibility for delivery.

GIS TECHNOLOGY-BASED ROUTING ISSUES

- **Delivery Route Planning and Optimization** – A GIS-based routing allows for route optimization depending on various organizational needs and criteria. Routes can be prioritized for total delivery time, to minimize fuel consumption, or to ensure a location will receive delivery service at a specific time.
- **Service Area Planning and Optimization** – GIS-based routing can generate optimal service areas based on the location of a main distribution point and desired service area characteristics, such as dedicated delivery times and number of delivery stops.
- **Inherent Model Sophistication** – GIS routing based on a sophisticated, configurable transportation data model allows organizations to accurately represent and solve their unique transportation requirements.
- **Incorporate Operational Rules** – Unique operational rules can be created in the GIS-based routing model. For instance, if left turns are prohibited within the organization due to safety and fuel-efficiency concerns, the model can be configured in such a way to ensure the resulting routes will not have any left turns.
- **Routing for Operational Contingences** – GIS-based routing can define optimal routes as operational conditions change, including staff absences or fluctuations in cargoes and parcel loads.
- **Routing for Construction and Emergencies** – Construction and emergency events can cause major disruption to transportation activities on campus. GIS-based routing can reroute deliveries around areas deemed off limits due to construction or emergency activities.
- **Integration with Mobile Devices** – GIS-based routing allows live route and directional information to be sent to drivers' smartphones or dedicated mobile devices.
- **Vehicular Tracking** – Coupled with GPS tracking, GIS-based routing can combine routing and live tracking data to track vehicular movements from a map-based display, providing operational visibility.
- **Data Capture/Organizational Intelligence** – GIS-based routing can capture GPS tracking and routing data vital to operational planning. Data analytics can be used to further refine and optimize routes and to holistically understand how deliveries are being made on campus.

Near-term Recommendations

- Promote the importance of sense of place through sustainability education, such as the Healthy Campus Initiative and health and wellness efforts now taking place.

- Seek understanding of campus stakeholder (students, faculty, and staff) attitudes toward mobility needs.
- Collect infrastructure data in coordinated fashion to set an appropriate mobility course for the future.

Long-term Recommendations

- Create physical spaces and buildings that provide a multiuse dimension and create a public realm.
- Develop a sustainability plan for campus that includes environmental, social, and business elements, such as the Harvard Sustainability Plan.
- Commit to implementing complete streets and accelerating bike lane implementation.
- Use mobility as an element of planning and creating incentives for dissuading parking directly on campus while ensuring that mobility choices are available. Flexibility and coordination must be incorporated.
- Commit to involving students, faculty, and staff in the planning process.

MOBILITY TECHNOLOGY

MSU MOBILITY TECHNOLOGY COMMITTEE

Biswas, Subir (Electrical and Computer Engineering)
Deb, Kalyan (Electrical and Computer Engineering /BEACON)
Gates, Tim (Civil and Environmental Engineering)
Ghamami, Mehrnaz (Civil and Environmental Engineering)
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Pierce, Graham (Univ. Outreach and Engagement)
Liu, Xiaoming (Computer Science and Engineering)
Moore, Sharlissa (James Madison College/ Civil and Environmental Engineering)
Potter, Tim (MSU Bikes)
Prush, John (MSU PD Management Services)
Radha, Hayder (Electrical and Computer Engineering)
Weinfeld, Arnold (Public Policy Initiatives)
Verboncoeur, John, *sub-committee chair* (Electrical and Computer Engineering /CMSE)
Wilson, Mark (School of Planning Design and Construction)
Zockaie, Ali (Civil and Environmental Engineering)

OVERVIEW

A pilot mobility proving ground for the campus of Michigan State University (MSU) is proposed, which would enable MSU researchers to participate in the national development of technologies and processes for mobility related to connected and autonomous vehicles (CAVs), pedestrians, and bicyclists. MSU has more than 60,000 students, faculty, and staff and a contiguous campus-managed transportation network of more than 15 square miles ranging in profile from rural to suburban to high-density urban, making it an ideal place to develop mobility technologies for vehicles and infrastructure, as well as optimization and management tools. Concurrent with plans to upgrade campus infrastructure to enhance safety and efficiency, researchers will be involved in developing vehicle technologies, infrastructure technologies, and system integration technologies that enable real-time optimization and management of routine and emergency mobility on campus. The area known as Spartan Village provides 330 acres with multiple roadways and two ingress points, which can be gated to provide a controlled development and test environment for CAVs and related vehicle and infrastructure technologies. Deployment of commercial automated electric buses, enhanced with services such as automated coffee and connected infotainment, will provide practical connections between parking and working sectors of campus. Enhanced bicycle services will provide a managed method for on-campus mobility. Enhanced pedestrian safety and optimization services can be deployed through mobile devices interacting with campus infrastructure. Smart infrastructure can be used to control traffic signals for enhanced safety and platooning of cars and pedestrians to reduce stoppages. The proposed pilot mobility proving ground will enable MSU to share technologies, data, processes, and policies with other campuses and urban centers to improve safety and efficiency of urban mobility systems nationwide. This coordinates well with ongoing research activities on campus and establishes MSU as a mobility innovation site specializing in technologies for pedestrian-intense mobility, such as college and corporate campuses, urban centers, resorts, and retirement communities.

The field of transportation engineering seeks to develop innovative and practice-ready solutions that improve mobility, accessibility, and safety in a manner that is economical and sustainable. To that end, it is crucial to study the impact that CAV system technologies will have on accessibility, mobility, and safety of transportation systems, while using the results to guide proper infrastructure planning and design. The transportation area group housed

within MSU's Department of Civil and Environmental Engineering has been extensively involved in research on transportation safety, mobility, and infrastructure planning. Following are brief summaries of how the transition from human-operated vehicles to autonomous vehicles will impact traffic-related research in these areas.

SAFETY IMPACT

Each year, more than 32,000 people die on U.S. roadways. Although this number remains unacceptably high, life-saving progress is clearly being made (more than 40,000 persons were killed a decade ago) through various nationwide policy initiatives, including the federal Toward Zero Deaths initiative. MSU also benefits strongly from having its crash data included in the award-winning Michigan Traffic Crash Facts website, which provides convenient public access to the official annual crash data minus personal identifiers for all public roadways in Michigan.

Nevertheless, numerous transportation safety issues persist. Transportation safety researchers at MSU have been working for decades to identify and address such issues to create a safer environment for all users of the transportation network. However, the safety impact that will result from an increasing presence of CAVs remains unknown.

Several recent projects by MSU researchers have considered the safety-related impact of transportation policies involving speed limits, roadside safety devices, highway rumble strips, traffic signalization techniques, roundabouts, and pedestrians and bicyclists. However, none of these projects considered the impact of CAVs. Although such vehicles are expected to improve efficiency and safety by reducing the human influence on vehicle operation, other human factors and behaviors remain due to pedestrians and bicyclists, who are particularly vulnerable.

Traffic control devices, including pavement markings, traffic signs, traffic signals, and work zone delineation devices, are another area in which the transition from human to autonomous driving will have a substantial impact. This means that all plans, designs, and strategies will gradually need to consider increasing penetration rates of connected vehicles and later automated vehicles with varying levels of automation. For example, to assist with lane positioning of an autonomous vehicle, pavement markings will need to be interpretable and consistent across all jurisdictions and during all weather conditions and times of day. Deterioration must be considered, as degraded markings will inherently provide diminished contrast for machine-vision systems to interpret. Similarly, highway guide signs, which are notorious for being inconsistently applied throughout the United States, must also undergo a full review for consistency and readability by autonomous vehicles. Traffic signal timing, particularly during the change (yellow) and clearance (red) intervals will also be affected, as the reliance on human reaction and response to these signals is diminished.

Perhaps the most challenging traffic control device aspect related to autonomous vehicles involves highway work zones, due to the dynamic nature of this environment. All work zone traffic control devices—such as channelizers, pavement markings, signs, and barricades—must be designed to accommodate both humans and vehicle-sensor technology. CAVs present unique challenges when presented with the particular characteristics of work zones, including unusual traffic routing patterns and the presence of workers, work vehicles/equipment, and traffic control devices all within very close proximity to travel lanes. As a result, work zones may require specific devices and instruments to accommodate CAVs. Roadside infrastructure for vehicle-to-infrastructure communication will need to be strategically placed both in advance of and within the work zone. Because work zones likely present conditions that would require transfer of autonomous control back to the driver, it will be necessary to alert the vehicle and driver far ahead of the work zone so control can be safely transferred in advance of the work zone. Finally, for automated vehicles that work with exact GIS data, it will be necessary to update the modified GIS information for the work zone area and provide driverless vehicles with the updated information.

MOBILITY IMPACT

For decades, the dynamics of traffic congestion in urban areas have been modeled using a variety of network traffic simulation tools. Although simulation has long been used to model network travel patterns, connected vehicles will not only change the fundamental input parameters for simulation models—including spacing, capacity, reaction time, acceleration performance, and braking performance—the vehicles will also provide input data for use in the computer models. Furthermore, the influx of CAVs will greatly impact the algorithms used in network modeling software, requiring recalibration and revalidation of mobility models to account for a shift away from optimization for individual users to network optimization.

In addition to congestion, travel time uncertainty is also present in transportation networks. Traffic incidents, work zones, weather conditions, special events, traffic control devices, fluctuations in demand, and inadequate base capacity are sources of these uncertainties. Different users have different responses to this travel time uncertainty based on personality and risk acceptance. On the other hand, the data collected by CAVs will provide important travel-time distributions for these models. Also, the real-time information on congestion patterns and special events can be used to improve network reliability.

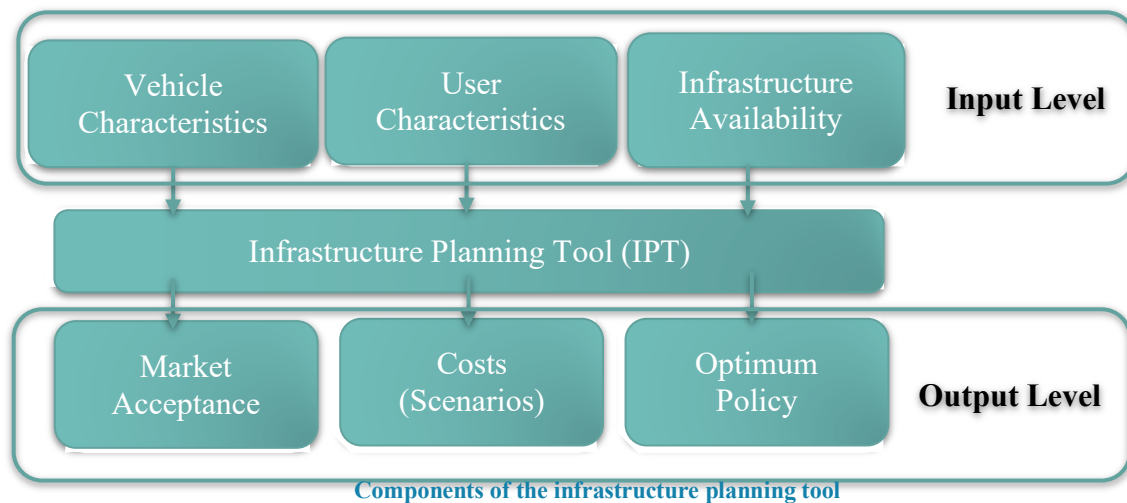
Another area in which CAVs may play a major role relates to minimizing the disruptive effect of inclement weather on traffic congestion and delay. The Federal Highway Administration's Road Weather Management Program has been involved in research, development, and deployment of weather-responsive traffic management strategies and tools. CAVs will decrease the weather-disruptive effects significantly, and these effects will need to be considered in traffic estimation and prediction systems to improve the capabilities of weather-related strategies and tools.

TRANSPORTATION INFRASTRUCTURE PLANNING

With the increasing market share of CAVs, planning for the infrastructure to communicate with these vehicles has attracted more attention. Connectivity of vehicles along with the availability of infrastructure affects the market acceptance of these vehicles. Thus, optimization of the level of this connectivity or the level of information sent/received, while considering the tradeoffs involving cost, safety, and market share, is necessary. Recently, the focus of the MSU transportation area group has been on optimizing policies affecting various types of alternative fuel vehicles, specifically electric vehicles.

The infrastructure planning tool (IPT) the group developed has the ability to predict market evolution of different vehicles' sales by gathering information on users, vehicle type, fuel and maintenance cost, availability of infrastructure, and the expected growth rate. The IPT analyzes the data and proposes an optimum policy, including improving and expanding current infrastructure and/or diverse pricing scenarios, and can be used to test various pricing and planning scenarios. IPT outputs include cost and emissions from each policy, an optimum policy with minimum cost and emission, and market share evolution of these vehicles through the life of the study. IPT modification to incorporate CAVs and their characteristics—including the level of information disseminated to predict market acceptance and revenue generated from these vehicles—will be necessary.

Recent developments in the field of mobility include the development of CAVs, smart infrastructure, and hardware and software mobility management tools to integrate the technologies into a system capable of optimizing and managing urban mobility. Mobility optimization and management can enhance both efficiency and safety by managing the interactions between vehicles and among vehicles, pedestrians, and cyclists. Optimization may include reduction of time to destination, maximization of fuel economy, minimization of emissions, and reduction in interactions with cross traffic, pedestrians, and cyclists using a centrally managed combination of vehicle, infrastructure, and personal electronics technologies.



For example, platooning vehicles and pedestrians using smart traffic signals so that cross traffic arrives at intersections alternately can result in fewer stops and less time waiting for all, with resulting benefits to safety and efficiency. These techniques, when scaled for urban areas, can also have measurable effects on emissions, so that smog-prone areas can experience improved air quality as well as a reduction in fines for violations. Management of peak mobility events, including large sports or other entertainment events or emergencies, is also possible with a system approach.

Mobility interactions are a particular challenge on university campuses where cyclic classes and vehicle traffic peaks at the start and end of the workday as well as during the lunch hour result in significant variability. MSU has started to address pedestrian and vehicular traffic optimization with an eye on improving traffic safety, enhancing vehicular flow, and reducing pedestrian commute time between buildings. MSU has already initiated plans to upgrade key features of the transportation network, including traffic signal controllers, sensors, and data collection devices.

MSU has more than 50 acres of parking lots, which are connected to the teaching and research facilities via on-campus bus routes. The bus system has an on-campus hub, which was established a decade ago, and connects the university to the regional public transportation system through a partnership with the Capitol Area Transportation Authority. Connecting the various commuter parking lots to central campus and the public transportation terminal is one of the projects MSU envisions as a future use of autonomous vehicles on campus.

PARKING TECHNOLOGY

There are several technological solutions for parking access control and capacity analytics. Based on existing infrastructure, space restrictions, and fiscal constraints, the best option for the MSU parking system is a combination of boom gates and induction loop vehicle detection pavement sensors.

The MSU Police Department, Management Services Bureau, is actively updating the aging Federal APD Inc. parking gates installed at several parking lots across campus. Maintenance of this equipment is challenging as spare parts are sparse, and the system does not provide any utility for analyzing and publishing parking usage data.

The new parking gates, part of the T2 Systems PARCS solution, operate more quickly and are deeply integrated

into the parking management software system. Now, when parking permits are issued, Spartan ID cards are activated for use at the parking gates in real time.

Along with the new gate and card reader equipment, radio frequency identification (RFID) wireless tag readers are also being installed. The TagMaster brand equipment, similar to the readers installed for toll roads, enables the use of RFID permits, which will raise the parking gate when authorized vehicles drive up. Testing has been successful, and 2019 parking permits will have RFID tags embedded for use at these parking gates.

Furthermore, induction loop vehicle detectors implanted in the pavement of the entry and exit lanes where gate arms are installed will also be replaced where the infrastructure is deteriorating. These sensors, which consist of a loop of wire set into the concrete, can provide vehicle count data to the central parking management system. This usage data, which tallies the number of cars entering or leaving the parking lot, is intended to be published to a future website, where third-party smart phone applications may acquire the data for driver use. This will allow drivers to make decisions about where to park, based on availability, before arriving on campus.

With regard to specific spot detection, research studies have shown that magnetometer sensors coupled with infrared sensors provide higher accuracy with lower maintenance requirements for outdoor lots, while ultrasonic detectors are the best option for indoor lots. For limited applications, ultrasonic detectors will be installed to monitor specific parking spaces for availability. In this configuration, usage data for particular types of parking spaces, such as accessible spaces or university vehicle spaces, can be monitored and analyzed.

MOBILITY STUDIO

MSU recently developed a system approach to mobility called Mobility Studio, which includes three key components: Connected Autonomous Networked Vehicles for Active Safety (CANVAS), smart infrastructure, and mobility optimization and management. Research is under way in each of these areas within multiple colleges throughout MSU; and plans to study and deploy technologies to enhance campus safety and efficiency are under way using a combination of developed and commercial technologies in collaboration with industry, other academic institutions, and the Michigan Department of Transportation.

Key areas of research, such as cybersecurity and connectivity, are common across the component areas of Mobility Studio. Integration of these technologies with existing commercial technologies for CAVs and smart infrastructure as well as personal electronics such as mobile phone technologies can be used to enhance safety and improve mobility services.

Key areas of research also include social aspects, macro and municipal economics, urban planning, business and finance implications, human-machine interface research, and policy and legal considerations. The transformation of mobility in the form of both hardware and new services will have a major impact on how people work and play and has the potential to reshape modern civilization in ways that are not yet predicted. This will require extensive research well beyond the technologies that are the focus of this report.

CANVAS

CANVAS is a comprehensive and integrated initiative that can enhance state-of-the-art and key sensor, data fusion, and deep-learning technologies at MSU. More specifically, the CANVAS vision is centered around three areas of research in which MSU engineering faculty members have been making key contributions:

- Electromagnetic-based sensing and analysis
- Visual and lidar sensing and analysis

- Connected vehicle networking and cybersecurity

By integrating its strengths and expertise in these areas, MSU can position itself to take a clear leadership in multiple strategic efforts related to the automotive industry

It is clear that many leading automotive manufacturers have developed advanced technologies for active safety in support of their collision warning and avoidance systems. Ongoing research at MSU can make key contributions toward helping the automotive industry further enhance state-of-the-art systems. Evidence of such contributions includes close interactions of MSU's electrical and computer engineering faculty with key players in the auto industry and, more important, recent support that faculty members have received from major players in the area of accident avoidance through active safety.

A crucial aspect of the CANVAS initiative is the integration of visual scene analysis, radar, and electromagnetic-based sensing with efficient, real-time, and secure connected vehicle networking. The vision for this integration is to move active safety to a level of performance beyond what can be offered based on current state-of-the-art solutions. In principle, current active safety technologies primarily focus on the particular, individual vehicle that is being supported and whose environment is being sensed and monitored with minimal communication or sharing of vital information with surrounding vehicles. Although this may provide adequate safety for individual vehicles, it can't guarantee the best optimal safety scenario for all of the vehicles, pedestrians, and cyclists within a given scene. CANVAS will move toward sharing and exploiting, in real-time, the collective data sensed and captured by multiple nearby vehicles to paint a more robust and safer picture for all vehicles and people within a given situation. This networked-based approach to active safety will represent a cornerstone for CANVAS research at MSU. Additionally, development of cybersecurity mechanisms for connected vehicles will be crucial for the viability of these networked vehicles.

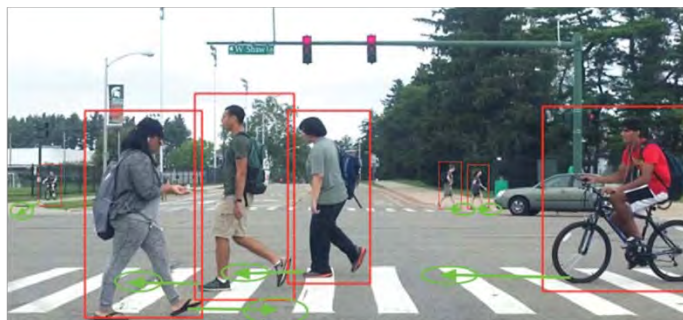
Since autonomous cars represent a crucial and strategic direction for the automotive industry and technologies developed for active safety are inherently related to autonomous vehicles, CANVAS-related activities could play a major role in positioning MSU as a key player in autonomous vehicle research and development. This could lead to strategic relationships not only with traditional industry manufacturers but also with emerging key players such as Google.

Activities could include an education and outreach component for the automotive industry, government agencies, and other players with specialized and online courses on specific topics of interest to engineers, managers, and researchers within the auto industry. Topics could include antenna design, electromagnetic interference and compatibility, mobile and sensor networks, image processing and computer vision, and advanced signal processing.

SMART INFRASTRUCTURE

▪ **(joint) deep learning**

Object detection, recognition & motion forecast using deep learning



Recent technology advances are rapidly transforming transportation infrastructure and enabling new capabilities

that can impact CAVs and conventional vehicles alike. As one of the leading academic institutions in machine vision, pattern recognition, and deep learning, MSU has many opportunities for development of smart infrastructure application. The development of cameras on traffic signals enables moving from timed signals to smart signals that can adjust for actual traffic conditions in order to minimize wait times or recognize vehicles by type and determine trajectories that will exceed stopping capabilities and mitigate accidents by holding lights slightly longer.

One of the key advantages of an MSU mobility proving ground is testing in four seasons with rain, snow, ice, sand, leaves, and water to obscure lane markings and interfere with signals, visual sensing via cameras, and lidar, as well as radar. Overcoming these challenges is required for full autonomy and will require technological advances in infrastructure. Furthermore, deployment in the vast majority of U.S. roads that lack access to power requires new technologies for providing lane markings in poor visibility. MSU has developed networked vibration-harvesting accelerometers for measuring vibrational modes on bridges, with ongoing research on major Michigan bridges. Adapting this technology to provide lane markings in pairs to provide position and directionality, for example, can provide additional information for CAVs in rural areas.

MSU has one of the top groups in the field of electromagnetics in areas from sources to antennas to electromagnetic interference. These technologies will be key elements in mobility infrastructure in which directionality, range, and low power may be important features.

MOBILITY MANAGEMENT

The focus of transportation infrastructure planning is on providing mobility and accessibility through various land uses and communities. Urban planning studies and the businesses in an area have mutual effects on one another. Businesses, especially production units, need to consider infrastructure planning for their success. The transportation infrastructure planning team at MSU has conducted advanced research in policy optimization to move people and goods through the network. The overarching goals include, but are not limited to, maximizing market acceptance, mobility, environmental benefits, and safety while minimizing both manufacturing and user costs and emissions of different types of vehicles and infrastructure.

These planning studies consider the tradeoffs within the system that result from conflicting interests in the system. MSU's transportation infrastructure planning team has researched these tradeoffs for alternative fuel vehicles in recent studies and is currently investigating them in emerging CAVs.

With the increasing market share of CAVs, planning for their infrastructure has become crucial. Safety concerns rise when there is a mixed fleet of conventional and autonomous vehicles on the road. These concerns can be addressed by the amount of information transferred among the vehicles and between vehicles and the infrastructure. Since connectivity of vehicles, along with the availability of infrastructure, affects the market acceptance of these vehicles, optimization of the level of connectivity or the level of information sent/received—while considering the tradeoffs between cost, safety and market share—is necessary.

Producing these vehicles with various communication capabilities affects the supply chain of the production line through time. With a mixed fleet of vehicles on road, the supply chain of conventional and autonomous vehicle parts should also be combined and designed to minimize the total production cost, while maximizing the production pace and the market acceptance of the produced vehicles.

MSU is studying campus mobility and existing commercial smart infrastructure along with developing technologies and processes with plans to upgrade campus infrastructure in two key areas: safety and efficiency. The key safety goals are reduction in vehicle–cycle–pedestrian encounters and elimination of human error. For combustion-powered vehicles, efficiency is defined as tenability among time to destination, fuel economy, and greenhouse gas or other emissions. For electric vehicles, the efficiency goals include time to destination, battery range, and battery lifetime. These goals may be achieved by an integrated system approach in which vehicle and

infrastructure are monitored and controlled by a central system designed for tunable optimization.

CAMPUS ADVANTAGES

ENHANCED SAFETY

The MSU Police Department has more than 80 officers with police authority on a campus that encompasses more than 15 contiguous square miles. John Prush, deputy director of the department's Management Services Bureau, will be the designated safety officer for the proposed pilot mobility proving ground. His team will also be in charge of storing and appropriately sharing data on testing and operating autonomous vehicles on campus.

MSU is committed to developing and sharing data and approaches to enhancing safety developed at the proposed mobility proving ground, including data obtained in controlled tests as well as operational data. With mobility densities ranging from high-density, pedestrian-intensive sectors to low-density, agricultural sectors, as well as train tracks, a power plant, and one of the largest campus-run food and residence hall systems in the nation, MSU can offer unique data on many types of interactions. It also has a population open to new technologies, the benefit of four seasons, and all the equipment required to manage large, diverse facilities.

PROPOSED CONTRIBUTIONS

The proposed mobility proving ground will enable contributions in a number of key areas. With the wide range of mobility densities from rural to pedestrian-intense urban and its four seasons, MSU will offer opportunities not available on corporate test tracks. Along with MSU-developed CAV and infrastructure technology, as well as integrated mobility monitoring and management software, the MSU proving ground can support advanced situational testing opportunities. MSU intends to be a leader in the area of system integration and hosting CAV and infrastructure testing will provide the basis for system architecture research and development.

MSU has its own CAV program and will also review applications for corporate and academic institutions requesting use of the facility. In particular, testing of heterogeneous components is of particular interest.



MSU will participate in the Mobility Community of Practice, including data and process sharing and hosting workshops that bring together top researchers and companies developing large-scale mobility solutions. As the site of the National Center for the Preservation of Pavement (NCPP) and a U.S. Department of Transportation (USDOT) University Transportation Center on pavement research, MSU has a strong record as a national leader in

the area of pavement preservation. The NCPP provides workshops on best practices and methods that will serve well in dissemination of mobility information. MSU anticipates increased ties to the Michigan Department of Transportation and USDOT, through both research and development activities and the sharing of best practices via publications, workshops, and conferences on and off campus.

COMMITMENT TO SAFETY

MSU has established a standing committee on safety and security, which will meet quarterly to unify communications among the MSU Police Department, the Department of Information and Technology Services, emergency responders, and various interested campus units. Wolfgang Bauer, senior consultant to the executive vice president, Administrative Services, currently chairs this committee. John Prush, deputy director of the MSU Police Department's Management Services Bureau and designated safety officer for the proposed pilot mobility proving ground, will be a committee member to provide effective communication between the project and the campus community at large.

Richard Enbody, associate professor, Department of Computer Science and Engineering, leads a team of undergraduate and graduate students and staff working on developing cyber-defense skills in the automotive domain. Enbody's team developed a protocol utilizing the Common Vulnerability Scoring System that can be applied to cyber-attacks on vehicles. In addition, the team has been analyzing a Ford-supplied instrument cluster to develop cyber-attack skills while probing for vulnerabilities.

RESEARCH APPLICATION AND DATA SHARING

MSU is capable of hosting data acquired from mobility testing and making that data available to collaborators. Data ranging from the training data for deep-learning modules in CAVs or smart infrastructure can be acquired in operations and post-processed to improve algorithms for decision making both internally and externally. MSU is also a planned collaborator in MCity in Ann Arbor and the planned American Center for Mobility and will seek to fuse the data from the varied experiences at all these sites as well as participate in efforts to make the data available nationally.

DEMONSTRATED INVESTMENTS

In the last few years, MSU has invested more than \$15 million in campus transportation to enhance emergency vehicle access and remove possible collision points with railroad traffic by building underpasses. During the previous year, MSU has begun installing cameras at intersections and set up the process of utilizing a traffic management software system to create an adaptive, connected traffic control system.

MSU has a campus master plan for locating new buildings, roads, and parking lots. This master plan, which provides a flexible framework for guiding the physical organization of the campus, is updated periodically in response to new initiatives. The campus mobility plan now under discussion will interface with the master plan and provide a framework to improve campus mobility for all.

MSU has invested in a fully instrumented Lincoln MKZ automated vehicle outfitted by AutonomouStuff. In addition, Hayder Radha, professor, Department of Electrical and Computer Engineering, leads a team of faculty and students developing improved sensors, acquiring data for deep learning to train the vehicle, and developing data fusion capabilities to improve performance.

MSU is also one of eight domestic participants in the Society of Automotive Engineers—General Motors Autodrive Challenge, which includes provision of a Chevy Bolt and the hardware to make it fully connected and automated.

A student Connected and Autonomous Vehicle (CAV) club team has acquired a golf cart and is building sensors and control capability to make it fully automated. This lightweight electric vehicle is far more compatible with pedestrian-intense environments due to its moderated speed, low mass, and short stopping distance. This type of vehicle can give MSU a distinct competitive advantage in envisioning the future of mobility.

READINESS

MSU's campus mobility planning consists of three subcommittees: mobility source management, infrastructure, and technology and optimization. These subcommittees are responsible for readiness planning for the pilot mobility proving ground. MSU's Police Department will take the lead in designating areas that can be considered part of the proving ground, including expansion from initially closed tracks to the entire campus once sufficient safety protocols are in place. Significant portions of campus can be utilized immediately for pedestrian–infrastructure interactions, which entail a lower technological challenge for safety since changes in infrastructure timing and responsiveness follow existing pedestrian rules. In addition, data gathering via monitoring technology is already active.

ADHERENCE TO LAWS, REGULATIONS, AND FEDERAL POLICY

The responsibility to assure that the facility will adhere to current Michigan and federal laws lies within the MSU Police Department.

SPECIALIZED TECHNOLOGIES FOR THE PEDESTRIAN-INTENSE ENVIRONMENT

BICYCLIST INTELLIGENT DEFENSE SYSTEM

Students in the spring and fall 2018 ECE480 capstone classes will construct a battery-powered device similar to the LaneSight vehicle detection and warning system for cyclists being developed commercially but using video instead of sonar for cost reduction.

Using pattern recognition of video images or radar from a rear-, side-, or front-mounted bicycle camera/sensor, the device will be able to detect approaching vehicles and calculate their trajectory. The device will communicate via B2V (bicycle to vehicle) with its location, speed, and destination if available. If a collision is predicted, the device will warn the bicyclist and vehicle in the following ways:

- Flashing lights, including several camera flashes toward the approaching vehicle that will identify the vehicle and driver even at night when the vehicle's headlights are on
- An alarm sound
- Lights on the handlebars that will tell the bicyclist how to turn or adjust speed to avoid a collision
- Audio voice to a speaker in the cyclist's helmet with instructions that can also alert the rider about non-dangerous approaching vehicles

The device will also make a video recording for future reference if necessary.

Other possible features include using B2V and V2B (vehicle to bicycle) communications to share information about nearby vehicles that do not carry these systems or about road hazards. Two-way audio may be enabled between vehicles if the drivers wish as a way to reduce road rage by providing a polite mode of communication similar to pedestrians speaking while passing. These features are just possibilities and not all will be able to be completed in one semester.

Other recommendations for enhanced cyclist safety and utility include:

- Install an automated technology solution that will provide daily bicycle count and route data on transportation patterns to help inform decisions on infrastructure improvements
- Continue to develop and integrate a smart phone based-application, such as the MSU Mobility app, for wide use by the MSU community to provide data regarding route preferences of bicyclists and pedestrians for consideration in future improvements
- Develop a camera-based system to recognize cyclists approaching intersections from the wrong direction coupled with a hazard signal to alert drivers
- Partner with a large bike company and one or more car manufacturers to develop a robust motor vehicle-to-bicycle/pedestrian crash prevention solution
- Install separate bike traffic lights, which not only can give bicyclists some preemption on the cycle of the signal but can also time lights or give them priority

PAVEMENT/LANE MARKING TECHNOLOGY



Preliminary testing was performed using radio frequency identification embedded into the pavement under standard pavement markings. Preliminary results from Virginia suggest that such markings are detectable by CAVs in up to 12 inches of snow. MSU's College of Engineering occupies a leadership position in pavement research and will continue to implement and test different kinds of smart infrastructure hardware embedded into road surfaces. Of particular interest is the life expectancy of these types of sensors under real-world weather conditions found in Michigan winters, with repeated frost and thaw cycles, intermittent and sometimes heavy snow covers, and the necessary use of snow plows and salt trucks.

RECOMMENDATIONS

While test tracks, including many traffic scenarios, are in various stages of construction or deployment around the nation, no university campus currently has a large-scale test track with real buildings. Converting the Spartan Village area into a test facility will provide a unique facility, not only for the development of connected automated vehicle technologies, but also the deployment of new smart infrastructure technologies. The present buildings in the site provide additional benefits in terms of radar clutter encountered from real buildings, which

cannot be reproduced by the plywood buildings at other test sites. By gating the 330-acre facility off, a controlled system can ensure safety while enabling testing new hardware and software to high confidence levels, before bringing it to the public environment. This environment will serve as the first test for a number of technologies, to be improved, validated, and deployed to main campus or elsewhere when readiness levels indicate functionality, safety, and robustness have been addressed.

Candidates include vehicle automation algorithms, mapping, sensors including radar technologies up to mm wave frequencies, and sensor fusion technologies, parking algorithms, roadway sensors, signal light cameras with vehicle, bicycle, and pedestrian recognition and management. Control of this area, and its parking lots, would also allow dense vehicle maneuvers for parking, dense traffic navigation such as event ingress/egress, development of pedestrian/cyclist intense safety protocols, and weather testing of infrastructure, including interaction of snow removal equipment with smart pavement embedded sensors, utilizing MSU's strengths in pavements and sensors. Additional opportunities exist for development of automated snow removal equipment, including navigation in sparse and dense parking lots. Many of these capabilities appear to be presently unique, giving MSU researchers and corporate partners a competitive advantage.

In addition to full scale vehicle technologies, lightweight low-speed technologies (automated golf-cart scale vehicles) provide an opportunity for differentiation and mobility enhancement. Developing these vehicles in the parking-lot dense Spartan Village facility will provide a unique capability relevant to environments such as college and corporate campuses, retirement communities (including candidate uses for the Spartan Village facility 3-5 years out), resorts, and vertical urban environments. Partnering with a ride hailing provider, such as an Uber or Lyft, provides additional opportunities for this technology.

Parking technologies (T2 Systems PARCS + TagMaster RFID) can provide parking availability while minimizing searching. Campus buildout of this system should be completed. One enhancement to the parking system would be embedded magnetometers plus infrared for outdoor and ultrasound detectors for indoor specialty spaces (accessible, leased, campus vehicle) would provide additional capability in a second stage.

Lastly, it is recommended to improve the campus infrastructure bandwidth and storage to be able to capture vehicle and infrastructure data to the cloud. Here, MSU should seek opportunities to partner with DSRC, 5G, and other high bandwidth capabilities in order to study capabilities of each and provide a comparison in a device-dense environment including vehicles, infrastructure, and personal devices carried by cyclists and pedestrians. In the modern mobility environment, this bandwidth and storage technology presents one of the greatest challenges as engineers determine the amount and type of data needed, and how it will be used.

MSU MOBILITY RESEARCH APP

MOBILITY RESEARCH APP GROUP

Barnes, Danielle (Information Technology Services)
Bauer, Wolfgang (Administrative Services, Physics & Astronomy)
Mathew, Adi (Graduate Student)
Patterson, Morgan (Information Technology Services)
Qu, Tongbin (Planning, Design, and Construction)

OVERVIEW

Accurate location and speed data for each campus community mobility participant can greatly help with traffic and mobility planning and with improving commuting, parking, and traversing campus. To this end the 'MSU Mobility Research' app (Adi Mathew) was designed. In this first experimental version only a version for the iPhone was delivered to the campus community. Over 250 volunteers (students, staff, and faculty) agreed to download the app to their iPhones and leave it running during the semester. The app recorded daily data in intervals of up to 1 second and then uploaded them multiple times each day to a central server, which collected a total of 11,800 Megabytes of data.



Figure 6: Example for MSU Mobility App data collection

Figure 6 is a screen capture off the iPhone of one sample student and his path across campus on one particular example day. The colors on the path represent the speed with which the student moved at any given time.

The ITS group (Danielle Barnes, Morgan Patterson) developed a dashboard to provide a first idea of visualization of the aggregated data [Figure 7]. The data will be available for the entire MSU community, with the idea to crowd-source cutting edge visualization and Big Data analysis projects.

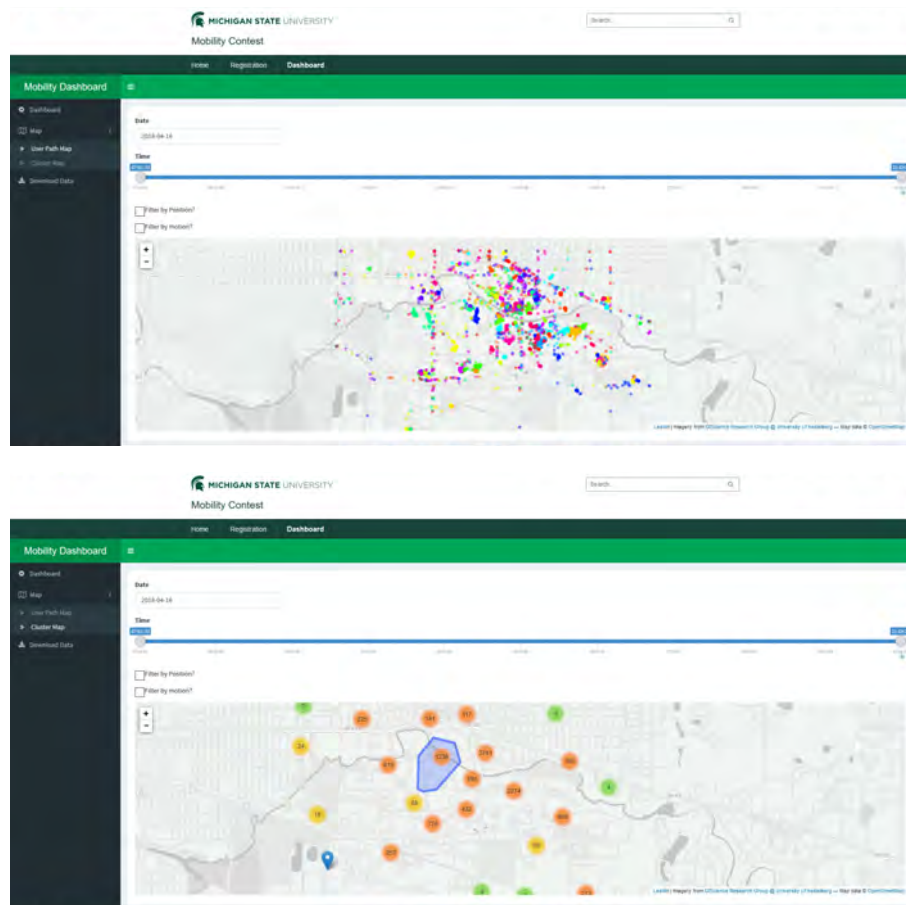


Figure 7: Screen shots of the Mobility App data analysis and visualization dashboard

MOBILITY APP FOR RESEARCH, TEACHING, AND LEARNING

Dr. Teresa Qu, Associate Professor of Urban & Regional Planning (URP) of the School of Planning, Design and Construction (SPDC) led the effort of teaching urban transportation and environment issues using the **MSU Mobility Research APP**, along with co-instructor Dr. Mark Wilson, in a university wide course UP100 “The City”.

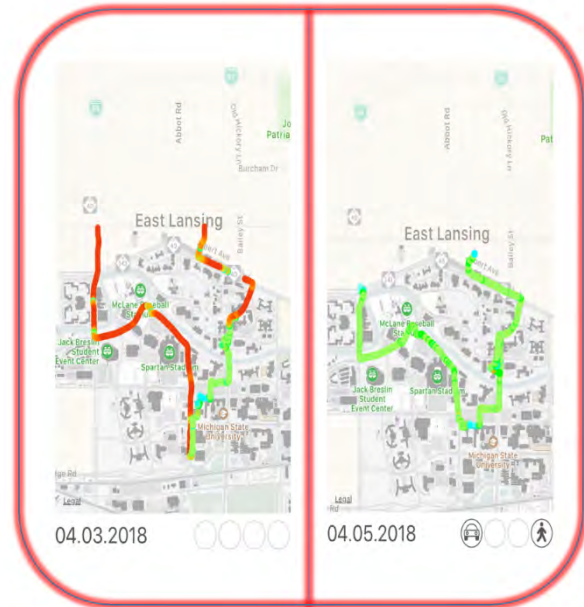
Students were assigned a transportation project that required them to record his/her own on-campus travel data on April 3rd and 5th and compare these two days’ travel associated with transportation mode, energy consumption, and carbon footprint (CO₂ emission). Students were encouraged to use different travel modes to compare the results. For example, if someone normally take buses to classes, they may ride a bicycle or walk to classes for one day for comparison purpose. There are two parts of the assignment. One is an excel dataset that documents each on-campus trip (obtained from **MSU Mobility Research APP**) and the calculated travel time, cost, energy consumption, CO₂ emission, and calories burned associated with each trip. The other is a written report that includes 1) the description and comparison results of the two-day trips and route maps (obtained from **MSU Mobility Research APP**), 2) if the students were assigned the job of designing autonomous bus routes on campus, their designed routes and their reasons for the design, and 3) if the students were assigned the job of designing bike share on campus, their preference of a station-based or a dock-less bike share and their reasons for the preference.

The UP100 class had 80 students in the spring semester of 2018. Below is an excerpt from one of the students’

report:

“Comparing walking and taking the bus produced some surprising results. It turns out that taking the bus was only faster by exactly 15 minutes. I had previously thought that the bus was much faster than walking, but it appears that walking is faster on campus, because you can walk across campus before another bus is scheduled to depart on its weekday bi-hourly schedule. Walking was a fifth of a mile longer, which I assumed is attributed to walking not being as linear as riding the bus. Though the bus may have been slightly faster, walking was still a much better mode of transportation due to a few factors. These factors include the calories burned, cost, energy consumption, and CO₂ emission. In comparison to taking the bus, walking was saved 60 cents per fare, burned an astonishing 225 more calories, and didn’t consume energy or emit CO₂. In conclusion, I found that although the bus was a faster method of getting around, walking is a much better mode of transportation for the environment and your fitness and finances.”

The university (MSU) also benefitted from the data that the 80 students provided. Mapping this dataset is helpful in understanding the spatial and temporal travel pattern on campus. The information will enable the university to make the campus safer, more efficient and sustainable.



TRIP 1 – CATA #25 & #24
Normal Commute

TRIP 2 – Walking
Campus Travel

FUTURE

After the first successful test run of the MSU Mobility Research App during the spring semester 2018 a foundation for mobility data gathering and analysis has been established. Crowd sourcing of analysis and visualization projects is now possible, and a data lake for a much greater data accumulation in the fall semester will have to be provided. As a top-100 research university in the world it is part of MSU’s leadership mandate to enable these types of projects for our students and faculty. They answer real-world research questions and at the same time allow us to improve our own infrastructure in the process.