Turning Point:
Shared Automated Vehicles Could Make Cities More Livable, Equitable
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Glossary

AV Automated vehicle. Partially or entirely replaces human driver.
CAV Connected and automated vehicle. Communicates with other vehicles and infrastructure.
SAV Shared automated vehicle.
MoD Mobility on demand. Includes taxis, TNCs, mobility shuttles for the disabled, and safe rides home for students.

Learn More

cts.umn.edu/research/featured/shared-automated-vehicles

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“Your Automated Vehicle is Arriving Now”

Fully automated vehicles (AVs), or driverless cars, will be commonplace sooner than you think. In fact, today’s new cars are already partially automated. Most have navigation systems, and some have automatic parking. Others have safety features such as lane-centering assist, collision-avoidance braking, adaptive cruise control, and sign recognition.

Right now, car makers and transportation network companies (TNCs) such as Uber and Lyft are steering AV development. They’re designing vehicles that early adopters with deep pockets will snap up. Without public input, this market-driven approach could worsen traffic congestion, sideline public transit, and increase social inequities. It could also hit state and local budgets hard, as revenues from taxes, parking, and associated activities dry up.

“How can local communities leverage emerging technology? Uber and Lyft have the data now to know how people move around. TNCs are using public roads, so there should be a benefit to the public from the data. Let’s put this money back into the community.”

—Zhi-Li Zhang

But it doesn’t have to be this way. New research centered at the University of Minnesota shows how, by planning carefully for AVs, we could make the most of this technology revolution to improve transportation and make it more equitable for all.

The quantum leap to AVs may seem distant—until suddenly, it’s here. The time to plan is now.
Planning for a Disruptive Technology

The policies set for AVs now will affect everyone for many years to come. We know this because we’ve seen a comparable disruption before. During the early 20th century, cities changed dramatically when cars replaced horses—in little more than a decade.

Cities accepted the role of providing roadway networks and eventually devoted up to half of their land area to car storage in the form of parking lanes, parking lots, and garages. As car ownership grew, cities and businesses arranged jobs and services around cars, disadvantaging people who couldn’t drive or afford to buy a vehicle. Transit systems were weakened or faded away.

This time, the revolution could be different. City and regional planners, elected officials, transit agencies, and TNCs could leverage the transition to AVs to address traffic congestion, social equity, and quality of life. Technology makes this transformation possible, but not inevitable.

How Do We Get There?

In this NSF-funded study, a large interdisciplinary team examined the potential of one approach: shared automated vehicles (SAVs). Led by Professor Zhi-Li Zhang, the team examined not only how SAV networks could work but also what the impacts on society might be.

Focusing on daily work commutes, the investigators looked at peak travel demands, traffic congestion, and rider needs. They asked: “What’s the best approach to deploy SAV technology? What would SAV systems look like? How would they affect jobs? Transit? Mobility for underserved populations? Land use?”

The team examined considerations around the rollout and regularized use of a hypothetical SAV system in a medium-sized metropolitan area: Minneapolis–St. Paul, known for its urban planning and varied weather.

The researchers worked with stakeholders, policymakers, and city officials to envisage the effects that SAVs could have at the local and regional level. They gathered data from transit agencies, city officials, drivers, riders, TNCs, and SAV tests in several locations.

They explored several scenarios with increasing levels of SAV adoption. (They did not set out to design or deploy such a system.) In developing these scenarios, researchers identified the issues that policymakers, planners, and mobility-on-demand companies must address to create an integrated system of SAVs—and, ultimately, a healthy, equitable, livable, and prosperous future.

This report gives highlights of their findings, along with recommendations for policymakers, in these key areas:
- Technological backbone for SAVs
- SAV operations and revenues
- Jobs and prosperity
- Public transit
- Social equity
- Land use and streetscapes

Waymo vehicles have logged more than 20 million miles on public roads and tens of billions of miles in simulation.

Teslas have gone over 3 billion miles in Autopilot mode since 2014.

Potential Stages of SAV Adoption

How far away is this revolution? Researchers disagree. Some say it will happen in 10 years; some say it will never be complete. Here are the characteristics to watch for.

Today: Experimenting and Paving the Way
SAVs are in limited use. Testing on roadways has begun.

Early Adoption
SAVs appear on city streets as part of daily traffic. Competing demands for infrastructure force choices to be made.

The Tipping Point
SAV trips outnumber human-driven trips. People see SAVs as cheaper and safer and begin to enjoy the benefits of new public spaces.

SAVs Are the Norm
The transition to AVs and SAVs is complete. Privately owned, human-driven cars are mainly operated by hobbyists.

Today
Car parking occupies 30 percent of the land in cities and 50 percent in suburbs, contributing to urban sprawl and environmental harm. Roadway construction and maintenance costs are high, and so are traffic injuries and fatalities. The distance between destinations makes many places difficult or impossible to reach by walking or biking. Travel obstacles disconnect people from jobs, schools, and services. Businesses can’t easily reach potential workers and customers. These obstacles reduce personal income, economic growth, and quality of life.

What are SAVs?
Definitions vary, but here are some basic concepts as used in this report:

- Shared automated vehicles might look like today’s passenger cars or shuttle vans. They could carry 2 riders—or 12.
- Instead of onboard human drivers, they could be controlled by a smart cloud computing system or by remote human drivers, similar to drone pilots.
- They wouldn’t be owned by individuals or parked in a homeowner’s garage. Off-duty, they could be housed far from riders.
- They could be ordered up for service the way Uber or Lyft rides are today. Or they might be small buses, part of the public transit fleet.
- They could take riders all the way to their destinations or connect them to light-rail or bus stops.
- They are now in the testing phase or in limited use as airport shuttles and goods delivery carts, for example.

Early Adoption
In this phase, SAVs mix with human-driven cars on the roads. The number of traffic crashes begins to drop. Small SAVs deliver most food and packages. This stage will be expensive, requiring investment in new infrastructure while maintaining existing roads and transit systems. Adding lanes or building new roads and parking structures may end up wasting money on 20th-century travel modes.

The Tipping Point
A majority of drivers have given up their cars in favor of mobility on demand, discovering that it’s cheaper and more convenient. Everyone spends less time in traffic as congestion eases. Travel gets safer. People of all ages feel more comfortable walking or cycling for transportation. Neighborhood densities rise as garages are repurposed. There’s less pavement and more green space. People unable to drive have more access to jobs and services, boosting prosperity.

SAVs Are the Norm
Most people subscribe to mobility services. Most private cars belong to hobbyists. If planners have made good choices, everyone has access to jobs, schools, and services across the metropolitan area. Business productivity has risen. Fewer people die in car crashes. The environment is cleaner. People may live more prosperous and healthier lives.
Findings

Technological Backbone for SAVs

Technology makes SAV fleets possible—there must be a way to control the vehicles from a distance. The research team examined two potential fleet management methods: a smart cloud computing system (SCCS) and tele-driving.

Smart Cloud Computing System

A smart cloud computing system, or digital backbone, would run an SAV system centrally. Zhi-Li Zhang and Yanhua Li developed algorithms for integrating ride-sharing systems with schedule-based transit. They prioritized traffic reduction and user convenience. Predictive traffic modeling and interviews with riders and professional drivers informed their models.

When they tested their approach using Twin Cities data, they found that the proposed SCCS framework could serve the trip demands of the Minneapolis–St. Paul metro with 22 percent fewer vehicles and 37 percent more vehicle utilization compared to using taxis to serve those requests. Using the SCCS, an SAV network could supplant and integrate most personal vehicles, low-ridership public buses, and taxis used in today’s private and public transport systems. The SCCS could enable a unified, on-demand, fast, convenient, and low-cost transport service for everyone’s daily commuting needs.

The team cautions that the success of an SCCS would depend on the scale of adoption. As with any new technology, such as the telephone in the early 1900s or the internet in the 1990s, a system is only useful when a critical mass of people use it. SAV providers, such as transit agencies or TNCs, would need to educate the public on SAVs and promote their use.

Tele-driving for Ride-Hailing Services

In another model, technology would combine nearly autonomous vehicles with remote “tele-drivers”—sort of like current drone operators. Tele-operated vehicles could keep humans in the loop and responsible for driving decisions, easing safety and public acceptance concerns about AVs.

A team led by Saif Benjaafar examined how using remote drivers could improve the efficiency of ride-hailing services. Today’s drivers move from low-demand to high-demand locations—repositioning that can cost them and their employers time and money. Remote drivers, in contrast, would be a common resource assigned trips by a central command center.

The researchers examined the impact of operating with more vehicles than drivers. Specifically, they wanted to see whether it would be possible to maintain the quality of service—customer wait time—if vehicles outnumbered drivers.

They considered two scenarios: one where customers are impatient and leave the system if they can’t be immediately matched with a vehicle and driver, and one where they are patient and willing to wait to be matched. The researchers modeled the dynamics of these two scenarios with a multi-server queueing model.
The models showed that whether customers are patient or not, a system with more vehicles than drivers can maintain or even increase the demand that can be served while improving the quality of service. Benjaafar says the results can be explained as tradeoffs between faster service times and more drivers, with three key factors at work: the number of idle vehicles, where vehicles are located (distant or close to pick-up sites), and pick-up wait times.

Besides efficiency, other benefits are possible. Tele-driving would eliminate the discriminatory behavior of onboard drivers who avoid locations they perceive to be unsafe. Personal safety issues (assault, harassment) would no longer be a concern for drivers and riders. Tele-drivers wouldn’t need to own a vehicle, broadening labor participation. And policymakers could set access and pricing regulations.

The researchers note that several pilots are demonstrating the commercial viability of tele-driving, including one by Vay (a German TNC) and several involving remotely controlled robots for food delivery.

SAV Operations and Revenues

How could an SAV network operate, and how could services be funded? Saif Benjaafar tackled these questions.

Revenue Models

SAVs could simply be incorporated into existing transit systems. Or, roadways and travel data could become assets owned by agencies, cities, or other regional authorities. Officials would write contracts with mobility providers to serve riders, and the resulting revenues would fund infrastructure. How could this work?

- **Fee-for-service model.** As TNCs do now, riders would pay for each ride, based on some formula of distance, demand, and time.
- **Subscription.** Some car makers have begun to offer mobility as a service, paid on a regular basis.
- **Advertising-funded SAVs.** These would make transportation free to riders, similar to broadcast television or websites.

Currently, TNCs do not share rider data freely, but they do mine it to build lucrative partnerships with other companies. Policymakers would need to consider regulation that protects rider data and ensures equitable access and pricing.

Jobs and Prosperity

SAVs could improve mobility for many people, connecting them to jobs and opportunities. So, in a broad sense, we could see economic growth and rising prosperity. SAVs will, however, disrupt one broad occupation: driving. Saif Benjaafar looked at these impacts.

The effect on drivers—whether at the wheel of a bus, Uber, taxi, or semi—will not be big at first. In the early stages, transit agencies, TNCs, and freight companies will likely use SAVs only in select situations.
Over time, things would change. The top expenses for transit agencies are labor and large vehicles that often run empty. AVs would let transit agencies efficiently assign drivers and vehicles to the right locations, possibly using remote drivers. Transit agencies could right-size vehicles to the number of riders in real time.

For TNCs, AVs also offer greater efficiency. Today, drivers spend a lot of time repositioning to chase demand. Some trips, especially in lower density areas, aren't profitable; some areas may receive no service at all.

Benjaafar’s team found that in the short term, with a mixed TNC system of onboard drivers and AVs, both service providers and drivers could make more money. Providers could accept more rides and increase revenues, and drivers could target the best locations and avoid repositioning, letting AVs handle less profitable calls. Longer term, drivers wouldn’t be needed. An integrated SAV network—with an umbrella view of demand and supply throughout the service area—could handle all rides efficiently, at lower cost, more equitably.

AVs may have the greatest utility for freight companies, which move goods throughout the day and night and are constrained by mandated rest periods for drivers. AVs could take long-distance routes while drivers make local deliveries to customers. Eventually, even those local deliveries could be handled by AVs. While the public is getting accustomed to AVs, the best application may be to move goods rather than people, Benjaafar adds.

“Over the next decade, we may see the widespread deployment of small robots to make deliveries or of large AVs to move goods long distance at night.”
—Saif Benjaafar

Public Transit

A common concern for a future of AVs is that they would siphon off many riders from current transit systems. However, a system of SAVs could work with—rather than replace—public transit. Alireza Khani took on this aspect of the study.

For many people, transit lines are not close to their homes or destinations. These commuters must either drive to a park-and-ride station or endure long transfer times. This service gap—known as the “first-mile/last-mile problem”—is the most pronounced in low-density population areas. Transit agencies have struggled to serve these potential riders—and SAVs could help fill the gap.

The researchers developed algorithms that incorporate rider and operator perceptions, demand estimation, pricing strategy, and subsidy strategy. This allowed them to evaluate different strategies for integrating mobility on demand (MoD) with transit systems. Public agencies and MoD providers should consider all of these factors when planning and designing an SAV system to serve a given area, they say.

By combining SAVs with existing fleets, agencies could right-size transit routes for the number of riders. Core transit systems would stay in place, and trains and buses would continue to serve densely populated areas. SAVs would replace low-ridership suburban routes. The cost savings from removing large but low-ridership buses could be invested in high-ridership routes, attracting more demand and increasing the quality of service.

The team warns that riders will avoid connections if they are unpredictable or slow or if they require separate booking and payments. MoD providers and transit operators should unify the booking and payment system and make connections efficient and easy.

“Integrating a core transit system with AVs in low-density areas could reduce travel time for riders and the overall cost of the system.”
—Alireza Khani
Social Equity

Automated vehicles have the potential to transform transportation services and improve mobility for many people—or they could worsen equity issues embedded in the existing system. Professor Yingling Fan and researcher Frank Douma co-led this portion of the study.

Researchers conducted interviews with several public agencies in the Twin Cities to gauge their priorities and concerns about the rollout of an SAV system. Through these interviews, they identified three groups of people who should be considered as equity stakeholders when designing and implementing SAV programs: people who are not well served by the current transportation system, people who may be negatively affected by SAVs, and people who may benefit from SAVs.

The researchers then designed three surveys to gauge public attitudes and preferences around SAV systems and identify differences based on demographic factors including race, age, household structure, gender, income, and health. One online study targeted Twin Cities metro-area residents, and a second online study targeted users of the ABC Ramps in downtown Minneapolis. A third survey expanded the research scope with an in-person survey of participants visiting the 2021 Minnesota State Fair.

From their analysis, the researchers found that SAVs have the potential to enable smart and connected communities where everyone benefits. SAVs could address the serious transportation equity issue of spatial mismatch—not only between home and work, but also between home and other activity destinations.

SAVs could also promote racial transportation equity. Black and Hispanic individuals in the Twin Cities currently face the highest rate of transportation difficulty and expressed the highest valuation of an SAV service compared to other groups.

Gender equity also surfaced in the analysis. Women significantly preferred security cameras or onboard attendants to an option with no security.

The team recommends that SAV systems be designed to ensure flexibility in booking and paying so that populations without smartphone access can use the systems. And to ensure widespread deployment, state agencies should consider the extent to which SAV systems could serve people outside of the Twin Cities urban core.

“If well-designed, communities employing pools of SAVs of varying sizes with efficient connections to high-quality public transit could bring about far-reaching societal change—providing inexpensive mobility services to all people, building stronger family and community ties, and boosting economic productivity and equity by removing mobility as a constraint.”

—Yingling Fan
Land Use and Streetscapes

SAVs will have far-ranging implications for urban design, land use, and streetscapes. Thomas Fisher’s team envisioned what that could look like.

Less Parking and Pavement, More Green Space

Mobility on demand and the widespread adoption of SAVs will reduce the need for parking. This could free up as much as 30 percent of the land area devoted to parking in many municipalities. While SAVs will reduce some municipal revenues, such as those from parking meters and traffic tickets, MoD will greatly increase the amount of land available for other, potentially revenue-generating uses like affordable housing, mixed-use development, and green infrastructure.

Private residences will likely change as well. As SAVs become widespread, homeowners will have garage space available for other uses such as accessory dwelling units, childcare facilities, home offices, and production space for small businesses. This will, in turn, require more adaptability in zoning codes to allow for a greater mix of uses and to give property owners more flexibility in terms of what happens in their homes.

Because of how precisely SAVs operate—with almost none of the “wander“ over the road that characterizes a driven vehicle—SAVs will create repetitive wear that could quickly rut roads, especially bituminous pavement. Just as our streets changed dramatically when we moved from horses to automobiles in the early 20th century, SAVs will require a roadway different from the ones we now have.

• To deal with repetitive wear, SAV-ready streets may only need concrete, grade-beam tracks where the vehicles operate, allowing for pervious pavers and planted surfaces for much of the road surface.

• SAV streets will also require fewer and narrower lanes. They can be equipped with real-time information and sensor technologies as well as wiring for vehicle recharging and snow melting.

• The fewer and narrower lanes of traffic will move the same number of people. This will also free up space for other activities in the public right-of-way, such as walking, cycling, and community gardens and gathering places.

As SAV streets become greener, they will also become healthier and safer. Heat-island effects, noise pollution, carbon emissions, and vehicle and pedestrian crashes will decline. Pervious street surfaces will reduce stormwater runoff while recharging aquifers. And the increased green space and wetlands in former parking lots will better handle and store water during major storms.

From Alleys to Arterials: Street Designs

The researchers created detailed designs for the four main types of AV-ready streets: alley, local, collector, and arterial.

Alley Street
Shared mobility will have a dramatic impact. As the need for parking goes away, garages will be available for other uses, while alleys become greener, safer gathering places for adults and children.

Local Street
When AVs become the dominant mode for vehicles, streets will only need a pair of tracks in each direction and no on-street parking—opening the right-of-way for green space, sidewalks, and bike lanes.
Collector Street
Broad SAV adoption will transform collector streets: The number of lanes needed will decrease and lanes can be closer together, freeing up curb space for picking up and dropping off people and packages. The extra space will allow for dedicated bike lanes, sidewalk-oriented activities, a denser tree canopy, rain gardens, and more.

Arterial Streets
Changes to busy arterial streets will be among the most striking: The number of lanes will drop, turn lanes will largely disappear, and traffic signals will only be needed for pedestrian crossings. Development can occur where parking lots and garages once stood, increasing density and expanding the tax base.

“We need to stop putting in 20th-century streets based on out-of-date assumptions about street design and start preparing for what is to come.”
—Thomas Fisher

Putting It All Together
From their analysis, the researchers say SAV systems are feasible—and possibly very beneficial—in communities like the Twin Cities.

Their individual studies show how the technology could work, who could own and operate fleets, and where revenues could come from. They show how SAVs could strengthen—not weaken—existing transit systems. They point to the economic benefits that could materialize and the potential for improving transportation equity. And they illustrate what future streets could look like.

“Could” is the operative word. Making it all happen depends on many important decisions. In the next section, the team offers key recommendations for policymakers, planners, and other officials to prepare for the next technology revolution.
Policy Recommendations

Public Engagement

Many people are skeptical that vehicles will ever be fully automated, while others are already concerned about issues such as crashes and data privacy. Officials need to get out in front and communicate with the public. SAV development should include public engagement—and should not be planned and controlled solely by private interests. SAV testing should be visible on public streets.

“Policymakers should support testing and deployment of SAVs so that people can see them on the roads and recognize that they are safe.”

—Frank Douma

Revenues

Revenue sources such as fuel taxes, parking fees, and fines will dry up. On the other hand, SAV providers that use public infrastructure and customer data could be a source of revenue. Land currently used for parking cars will be freed up for other revenue-generating uses. And private companies eager to offer mobility services to communities could be charged for the ability to provide those services, as transportation is increasingly treated like a utility. Communities should adjust budgets accordingly—and not sell the rights to mobility services cheaply.

“Don’t give away the store; be sure to have competitive bidding. Ask yourself, ‘What do we need in recompense for turning the mobility of our city over to a company?’”

—Thomas Fisher
Data Privacy and Sharing

Today’s TNCs have rich data on their customers, which they do not share. Cities and transit agencies that contract with transportation service companies for mobility on demand should control how data—and revenues from data mining—are shared.

Equity

The entire transportation system should be designed for diversity, serving all areas and different populations and user needs. Decision makers must represent all regions and stakeholders, and public input is a must.

One option is to conduct a transportation needs assessment to identify the hidden or suppressed travel needs of all potential travelers. Transit user surveys and driver surveys are not sufficient—they only reveal the preferences of people whose needs are already being served.

Transit

SAVs could feed existing public transit by solving the “first-mile/last-mile” problem. Policymakers should seek ways to use SAVs to connect people in low-density or poorly served areas to existing transit services. Transit may need to rethink its reliance on a “one-size-fits-all” approach by offering a wide range of services, vehicles, levels of convenience, and amenities.

Jobs and Businesses

AVs will disrupt jobs for many drivers. Policymakers should mediate this disruption. For example, they could incentivize TNCs to employ remote drivers from low-income communities for some applications.

Policymakers should ensure that drivers are fairly compensated and treated and that tele-driving is not outsourced to lowest-cost locations or even offshored.

At the same time, SAVs could connect people to jobs and businesses to customers, raising prosperity for everyone. Policymakers should consider how to deploy SAV services to low-density communities or those underserved by existing transit services.
SAV Fleet Management

Optimal Fleet Sizing
SAV fleet managers and TNCs should consider strategically placing SAV depots (parking and dispatching centers) across their coverage region. This will balance wait times for riders with costs and road congestion.

Pricing
Operators prefer dynamic, demand-based pricing to avoid costly repositioning, but riders dislike it. SAV fleet managers should consider fixed pricing, which will cover repositioning costs if the fleet is large enough.

Unified Booking and Payment
Riders prefer to plan their entire trip at once. SAV fleet operators should integrate their booking and payment systems with transit operators to make traveling more convenient and attract riders.

Safety
Today, Americans accept that car crashes cause more than 100 deaths per day. Driver error accounts for the majority of these—a factor that SAVs could eliminate. At the same time, a single AV crash can get major news coverage nationwide. How many SAV-caused crashes will the public accept? No one knows yet. Planners and policymakers should put the data into perspective for themselves and for the public as they consider how to regulate SAVs.

Technology
SCCS would require 5G internet at all points of service. SAV riders will need 5G internet as they travel throughout the service area.

“Do not be overoptimistic about technology alone. Trains and buses are not slower than cars because of the technology. They’re slower because we don’t prioritize them. Could we prioritize SAVs?”
–Yingling Fan

Land Use, Street Design, and Parking
Cities should start to plan how land that is currently devoted to parking can be repurposed to address sustainability, equity, and housing affordability goals. Public works departments should start to plan for narrower, greener roads; quieter, less-polluted streets; and the disappearance of storm sewer systems, as pervious road surfaces and constructed wetlands on former parking lots handle stormwater runoff.

Cities should also prepare to cut or eliminate parking requirements, allow for a greater range of uses in public rights-of-way, and provide more zoning flexibility. This will let property owners use their land and facilities for a greater mix of activities.

As fleet owners maximize the use of their SAVs and keep them in near-constant motion, cities should also plan for a reduction in the number of vehicles parked or on the road, as well as for an increase in demand for curb space.

US crashes due to human error: 94%
Traffic fatalities in Minnesota in 2021: 488 (preliminary total)