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Next Generation Mobility

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Contents

The New Mobility Services

The nations' surface transportation system is on the brink of a dramatic transformation driven by three revolutions (UC Davis, Institute for Transportation Studies, 2016):

- New mobility services and new traffic management systems enabled by a nearly ubiquitous high-speed communication system, new analytics and optimization techniques, and powerful smart phones.
- The shift from fuel powered to electric vehicles driven by both economic and environmental incentives.
- The possibility that automated, connected vehicles could eliminate the need for drivers in both passenger and freight vehicles.

These innovations could change US mobility options as powerfully as the introduction of the automobile. They could cut travel time and travel costs, provide mobility to people unable to drive or unable to afford conventional car ownership, improve safety, and cut vehicle emissions – including greenhouse gas emissions. But they could also go dramatically wrong if they encourage sprawl, clog roads with empty vehicles, or allow income inequality to translate into greater inequality in access to mobility services. One clear feature of these changes is that data and information technology have become as important to future mobility systems as vehicles and physical infrastructure.

The transformation is taking place at a rate that has largely outstripped the ability of the research community to understand what is currently happening, let alone develop the tools needed to anticipate future changes and guide private investments and public policy. Management of public infrastructure and public transportation systems are far behind private concerns in their access to data and advanced tools for analysis. Public officials often do not have the resources needed to collect data using modern tools, use the data to design and operate modern mobility systems or to participate effectively in systems that require close coordination between public systems and the sophisticated business models of private mobility providers. And they often lack the analytic tools to anticipate the impact of decisions on key metrics: including equity of service, safety, and the environment.

This paper will review the key areas of research needed to remedy these concerns. The paper will focus on understanding:

1. the new mobility systems made possible by the technical revolutions and new business models needed to support them.
2. new travel patterns induced by new systems including their impact on people now poorly served by the existing system
3. The key public policy issues that must be addressed to facilitate the introduction of new mobility systems that advance public goals including affordability, accessibility, safety, advancing environmental quality and mitigating global climate change.

While movement of freight will directly benefit from the policies discussed, most of the discussion will focus on moving people.

New Mobility Systems

Smart phones, smart devices and sensors embedded in vehicles and guideways, advances in our ability to collect and process massive amounts of data in real time, electric vehicles and rapid charging systems, autonomous vehicles, and other technologies are opening an extraordinary range of new options for travel.

Rapid change is already underway. Vehicle sharing, transportation service providers, and other innovations have seen explosive growth – Uber carried more passengers in New York City than taxis by mid-2017 (Hu, 2017). Ford, GM, and other major manufacturers are exploring selling "mobility as a service" instead of simply selling vehicles. The market has seen active experiments with services like Zipcar, City CarShare, Maven, Enterprise CarShare car2go and ReachNow (formerly DriveNow), Scoot Networks (Scooter Sharing), and Via (microstransit services). (Shaheen, 2016)

Successfully capturing their potential will require reimagining the vehicles, the guideways, control systems, and the public and private business models that have governed highway mobility for decades. For generations, the core assumptions about highway travel have been that vehicles would largely be owned and operated by individuals while roads and highways and their associated signaling systems would be built and operated by public organizations. Public transportation, walking, and biking were barely footnotes. These assumptions are now under vigorous attack but there is little clarity about the system that will replace them. It is entirely possible, for example, that new mobility services will largely replace private vehicle ownership, and new sources of data and new optimization methods will greatly increase the throughput on streets and highways. This may well create opportunities for radically new business models. The mix of public and private services will change as mobility information systems incorporate both private and public data. Public transportation may be redefined with new relationships between public and privately-owned vehicles that may "first and last mile" services. Electric utilities may want to play a major role in providing electric vehicle charging services.

The definition of transportation safety must be redefined since safety will increasingly depend not just on efficient management of data in the complex networks operating inside vehicles, but in the safety of an integrated mobility system based on enormously complex data management systems and the reliable interaction of large numbers of sensors in vehicles and in guideways.

The new systems also increase exposure to malicious use of the data to compromise privacy and provides opportunities for malicious actors to endanger individuals and entire mobility systems. Since the stakes are high, the standards for reliability and security of the data systems must be high.

The changes will also require a careful look a wide range of policy issues including:

- How to invest in roads, highways, parking, and public transportation
- How to acquire data needed to design and operate efficient transportation networks, including shared mobility systems that may be an integral part of public transportation
- How best to provide mobility services for the poor, the disabled, and others poorly served by conventional transportation.
- How to ensure physical and cyber security and safety
- How to integrate regulation of electric utilities with regulation of mobility systems

1. Elements of a Mobility System

The system of systems that provide mobility services are summarized in Box 1. All of them are likely to change dramatically in the coming decade. The changes will also have a major indirect impact on the many businesses that supply the mobility system.

Box 1
Elements of Mobility Systems

Urban Design and Physical Infrastructure:

- Design of roads, sidewalks, bike lanes, public spaces
- Parking
- Transfer stations (bus and transit stops, new mobility services)

Information infrastructure

- Traditional and next-generation signage
- Traffic controls
- Infrastructure to vehicle (I2V) systems
- Tolls, fares, usage fees, parking, fines

Energy Infrastructure

- Conventional fossil delivery
- Electric charging

Vehicles

- Fossil & Electric
- Automated and Connected (Level 0-5)

Vehicle sharing services

- Conventional car rentals
- Bike share
- Next generation, distributed car-rentals (e.g. Zip car, Maven)
- Shared personally owned vehicles (Getaround, 2017)

Trip Sharing Services

- Traditional bus, subway, trollies
- Traditional rideshare and slugging
- Traditional taxis
- Transportation Network Companies – including multi-passenger services (Uber, Lyft)
- Seamless Mobility systems.

Policy and Regulatory Frameworks

2. Urban Design and Physical Infrastructure

Choices made about urban design and the location and operation of roads strongly affect mobility options. Investments in infrastructure typically last for decades and care must be taken to ensure that additions are compatible with future system or, at a minimum, not discourage creative solutions.

The design of US cities, and the road systems that support them, have been designed around automobile travel for nearly a century. But there's growing recognition that current designs are simply not sustainable because of growing congestion, and environmental costs. Congestion costs the US about $120 billion per year (US Department of Transportation) and costs are even higher in other countries. Congestion reduces the gross domestic product of Asian economies 2-5%. (Asian Development Bank, 2017)

Driving in search of parking may reach 20-30% in extremely congested downtown areas but it appears that parking searches are responsible for 5-6% of VKM in the whole of San Francisco and 3-4% in Ann Arbor. (Weinberger, 2016) Roads and parking occupy a large fraction of urban space and often present impenetrable barriers, separating communities from each other or from amenities like parks and river fronts. And providing even limited mobility options for low income and disabled individuals has a very high cost. A system based on cars, largely with a single passenger, makes very inefficient use of highway infrastructure and the newly emerging transportation network companies (e.g. Uber and Lyft) are apparently contributing to congestion by putting more cars on the road. (Schaller Consulting, 2017a) (Gehrke, 2018)

A lot of thought has been invested in finding ways to design cities for people instead of cars. Several bold experiments have demonstrated what can be done both in designing new urban areas and retrofitting existing ones. (Sadik-Khan, 2016) (Speck) (Schwartz, 2015) (Walker, Human Transit, 2012) (Levinson) (Dunham-Jones, 2011) (Townsend, 2013) (Goldsmith, 2014) (Salat, 2017). The core goal is to return cities to people and make urban places safer, more environmentally sustainable, and more inviting. The designs involve new concepts in road designs, intersections, pedestrian zones to encourage biking and walking. New mobility systems have not been an integral to these designs, but the potential is intriguing. Most of the new systems do not rely on massive investments in expensive infrastructure such as new roads and rail lines but instead take advantage of the existing investments powerful mobile devices equipped with GPS mapping and other resources and cell phone communications. Expensive investments in new highway systems should be based on the new requirements being created by new mobility systems. It may well be that existing road systems are overbuilt if new systems finds a way to get more people where they want to go with fewer vehicles. Systems that keep most vehicles used and useful for a large part of the day could make parking largely obsolete; automated vehicles would accelerate the decline of parking. New investments will be needed to provide safe, easy-to-use transfer facilities to support transfers that may be needed by the new systems and facilities for vehicle charging will require major investments.

While new mobility systems may reduce highway maintenance costs by introducing lighter vehicles and reducing vehicle miles traveled, there will be a continuing need for maintenance investments if only to reverse the deteriorating condition existing roads and bridges (The American Society of Civil Engineers gave highway infrastructure a grade of D and bridges a C+ finding that one fifth of US highways are in poor condition which increased the maintenance costs of a typical car $533 in 2015. Nearly 10% of bridges were “structurally deficient”). (American Society of Civil Engineers, 2017)

The redesigned communities can be safer, in part because they are designed to encourage slower traffic speeds and because drivers become accustomed to seeing greater number of pedestrians and bikes. (Jacobsen, 2003) They can be healthier because of reduced emissions and because of the health benefits of biking and walking on a regular basis. Obesity is strongly correlated with neighborhoods where walking is perilous. (Go Boston 2030 Mayoral Advisory Committee, 2017) Moving from cars to shared services can also increase safety (see Box 2). People making the highest use of new shared mobility systems report owning fewer cars and becoming more physically active. (Murphy, 2016) Automated and connected vehicles may play a key role in improving safety when they enter the market. And smart street information systems can contribute by communicating real-time safety information to both vehicles and pedestrians (sensors on streets could warn vehicles of the approach of a pedestrian or bike and sophisticated street crossing signs, or perhaps apps, could warn pedestrians).

Box 2
Public Transportation and Highway Safety

- Cities where residents average more than 50 annual transit trips have about half the average traffic fatality rates as cities where residents average fewer than 20 annual transit trips
- Of 280 U.S. counties, the ten with the highest smart growth ratings have approximately a fifth the per capita traffic fatality rate as the ten with the highest sprawl ratings.
- many factors that increase public transportation use, such as good walking and cycling conditions, and compact development, also tend to increase traffic safety. Second, higher-risk groups, including youths, seniors, alcohol drinkers and compulsive texters, are more likely to reduce their driving if alternatives, such as public transit, are convenient and attractive

(American public transportation association, 2016)

A different set of challenges is faced in designing new mobility systems for areas outside dense, affluent urban areas – typically areas with a large population of the "young, rich, and childless." But a third of all US commutes begin and end in suburbs. (US Department of Transportation)

Poor urban neighborhoods are very poorly served. Recent analysis suggests that "The poorest tenth of households was 12% less likely to live in urban neighborhoods in 2014 compared with 2000, and 17% less likely to live in higher-density urban neighborhoods. In contrast, the richest tenth of households was 12% more likely to live in higher-density urban neighborhoods, and only 1% less urban overall in 2014 than in 2000." (Kolko, 2016) Areas where more than 20 percent of households have incomes below the Federal poverty line also face severe safety severe problems. These places have a pedestrian fatality more than 80 percent higher than the national average. Nearly 90 percent of high income neighborhoods have sidewalks while only 49 percent of low-income neighborhoods do. These areas also typically have poor street lighting, fewer marked crosswalks, and limited "traffic calming" installations. (Twaddell, 2016)

Cities will need to make a number of critical investments. They will need to:

- build on innovative urban design ideas already being considered to make cities more walkable and more livable (including investments in in poorer communities)
- increase investment in traffic signaling and sensors that can facilitate smart road management though much of this can probably be managed through cellular networks.
- invest in the people and equipment needed to design new mobility management systems and make effective real-time use of data from many different sources.
- create safe, comfortable transfer hubs with clear signage where "last mile" systems can transfer passengers to high-capacity/high-frequency buses or trains.
- convert land used for parking to other uses including enhance walking, biking, or "mini parks" (if, as hoped, the new technology will greatly reduce the need for parking).
- purchase a new mix of vehicles for public transportation.

3. Electric Vehicles

It's becoming obvious that avoiding disastrous levels of climate change will require policies that that shift the world's fossil-fuel powered vehicle fleet to electric vehicles or other carbon-free vehicles during the next two decades. (Sanderson, 2016) (Deep Decarbonization Pathways Project, 2015) Powerful forces are already at work. California Connecticut, Maryland, Massachusetts, New York, Oregon, Rhode Island, Vermont, Maine and New Jersey will require zero emission vehicles by 2025, Many major vehicle manufacturers have made significant commitments. In September, Xin Guobin, China's vice-minister of industry and information technology said that China would ban the production and sale of fossil fuel cars, although no date was announced. (Eichenberg, 2017) The shift will not be limited to cars. A recent Bloomberg study estimates that almost half of the world's municipal buses will be electric by 2025. (Chediak, 2018)

This will require a massive change in both vehicle and energy markets; US electric demand could increase by 10-20% by 2050. (Fox-Penner P. G., 2017) Given the large loads involved, connections between new mobility systems based on electric vehicles and the electric grid must be carefully managed. An ideal system would find ways to optimize the performance of the mobility system and the electric generation, transmission and distribution system simultaneously both in real time and in day-ahead or week-ahead planning.

A variety of business models can be imagined ranging from charging stations owned and operated by individuals to facilities owned and operated by public and private mobility companies. Organizations that own and operate a large number of vehicles may take the lead in introducing electric vehicles. The payback time for using electric vehicles would be relatively short since each vehicle would drive more miles per year than personal vehicles. Transportation Network Companies could remove concerns about "range anxiety" associated with electric vehicles using algorithms ensuring that vehicles can always meet their assigned deliveries with available onboard energy. It will be much easier to do this if electric vehicle ranges can be extended. In a recent survey of Uber drivers operating electric vehicles, half said that they'd have driven 10 hours more each week if they didn't lose time charging. (Gromis, 2018) It may also be possible for operators of large fleets to use vehicles which allowed discharged batteries to be replaced quickly. They would also be in a better position to ensure that components and software is kept up to date (US Department of Energy/EERE, 2017)

Owners of large fleets would also be in a better position to be integrated into the demand management systems of sophisticated electric utilities. They could, for example, be flexible in when and where they charge vehicles to optimize the performance of electric utilities. Electric vehicle charging could provide a variety of services (such as VAR control, frequency and voltage regulation) that they might pay EV charging. Electric Utilities will need to consider how best to coordinate their services with the needs of a large network of electric vehicles and charging facilities. They are already in the midst of designing new business models to reflect increased use of intermittent renewables, distributed generation, and sophisticated demand management end-user systems. (Fox-Penner P. , 2010)

4. Seamless mobility systems

A seamless mobility system would allow passengers to choose from a variety of systems for getting to their destination with options varying by timeliness, price, health, and environmental impacts. Any transfers needed would be free of confusion and waiting times brief. A single payment system would cover all the modes taken. (Kamargianni, 2016) A critical part of any such system is covering the "first and last mile" of trips – particularly getting people in less densely populated areas to places where they can transfer to high occupancy buses or other vehicles.

It is now possible to use state-of-the-art data collection and optimization tools to design and operate systems that would provide mobility services that are much more efficient and much less expensive. (Gruel, 2016) This will require optimizing the mixture of vehicle sizes (passenger capacity), transfer locations, and vehicle routing strategies. And it would benefit from a trip choice app that could give users a clear choice of options and a seamless payment system. Real-time pricing of different components will need to be incorporated. These systems could operate under a variety of public and private business models.

Enormous efficiency gains can be achieved with these systems since new data and analysis shows that the current system is hugely inefficient:

- most cars carry only the driver,
- buses travel with few passengers on off-hours,
- parking lots are full of cars that are operated only about 7% of the time.

Even taxis are poorly utilized. A recent study showed that an optimum use of New York cabs could cut the number of cabs in use by nearly a factor of 7 without reducing service. (Alonso-Mora, 2017) Taking this a step further, a city-wide system that optimizing vehicle size and vehicle routing, can dramatically improve the utilization of vehicles and reduce the number of large buses in use, while increasing service levels for all riders. Sophisticated optimization has demonstrated that a high fraction of trips can be taken with a single transfer from an on-demand van to a high-speed bus and wait times will not be longer than 3 minutes. Off-peak trips are best provided by eliminating large buses and using a shared van take riders directly to their destination (Von Hentenrych, 2017) Further gains can be realized if programs to encourage walking and biking are successful.

Autonomous vehicles would obviously be an asset to these multi-modal system by reducing costs and ensuring vehicle availability at off peak times. They would largely affect system costs by removing the driver. This might affect the choice of vehicle sizes and dispatch strategies. Among other things, they would not need to take drivers home and could be sent to optimized locations in off periods for storage and for vehicle charging.

There's still great uncertainty, new mobility options might reduce public transit ridership and the incentive for walking and biking. (Rayle, 2014) (Bliss, 2017)

A variety of natural experiments are now underway using existing technology.

- 14 percent of UberPool trips begin or end near a Metro station in Los Angeles and ten percent of UberPools begin or end at Bay Area Rapid Transit stations. (Shaheen, 2016) (Griffin, 2017)
- 25 percent of Lyft riders say they use the service to connect to public transit. In Boston, 33 percent of those rides start or end near a T station. And transit hubs like Chicago's Union Station, D.C.'s Union Station and Boston's South Station are among the most popular destinations for its users, Lyft finds.
- There's evidence that people using transportation network companies and bike sharing as integral parts of transit trips. (Kaufman R. , 2015 a) (Kaiser, 2012) (Manjoo, 2016) At present, however, about half of ridesourcing services are used for recreation or social purposes while only about 20% of trips are for commuting. (American Public Transportation Association, 2016)
- There is growing evidence that bikeshare users are using bikes to commute to transit hubs. (Faghih-Imani, 2017) (Campbell, 2017)

In spite of the limits placed on using public funds for using services that may not conform to the insurance or driver clearance process used by public transport, a variety of municipalities have experimented with using Transportation Network Companies to provide "first and last mile" services. These include Orlando and Pinellas Florida. The Pinellas system offers a 50 percent fare subsidy to riders using Uber or United Taxi service. The subsidy is roughly the same as the subsidy paid for the existing transit system. (TransitCenter , 2016 b) These hybrid systems clearly face challenges and there is growing concern that their use will prevent cities from deploying far superior solutions: "Emerging mobility providers can have a major analytical advantage given their laser focus on their own operations, flexible financial resources, and technical talent pool. This puts poorly resourced agencies at risk of becoming reliant on those providers to conduct trustworthy analysis to inform policy decision-making" (TransitCenter , 2016 b)

5. Other new business models

The new mobility systems, and the resources that support them, open a wide range of business opportunities, most of which have undoubtedly not yet been discovered. Some interesting new entrants include (Shaheen, 2016):

- Insurance Apps that allow users to pay for insurance based on the distance they travel instead of paying a fixed annual rate (e.g., Metromile). This would allow the companies to more closely align insurance rates with actual risk – which depends on the length and type of trips. Allstate has an insurance offering with fees based on travel distance, travel time, and safe driving. Metromile insurance uses a system where customers plug a GPS and cellular activated box into the vehicle's diagnostic port. Customers can use their app to choose between a variety of rates The company presumably can learn a lot about a driver's behavior and adjust rates accordingly.
- A variety of apps are available for finding parking (ParkWhiz, Best Parking, ParkMe, SpotHero)
- Peer-to-peer delivery services (private drivers deliver cargo) DoorDash, Postmates, Shipbird, and Shyp,
- Paired-on-demand courier (Transportation Network Companies carry packages as well as people)

Information Infrastructure

Road signs with changing messages are now familiar but, driven by modern communication and "smart phone" devices, mobility communication is about to move to an entirely new level. This will undoubtedly involve a mixture of public and corporate systems. The National Association of City Transportation Officials are emphatic, however, that "Traffic management will remain a function managed or regulated by the public sector even in a future dominated by private mobility providers. Public policies should foster open data platforms that enable robust private innovation to better serve transportation customer needs, while reducing aggregate social and environmental costs and inequities through a regulated utility model framework." (NACTO, 2016) The analogy to regulated utilities is intriguing since modern electric utility regulation has developed creative ways to combine private competition between suppliers while maintaining public management of the "natural monopoly" transmission and distribution systems – the equivalent to roads and highways. Some transportation agencies are now seeing their role as being "mobility managers" that provide a range of integration services that "go beyond a public utility model". (American Public Transportation Association, 2016) The Electric Utility Industry uses Independent System Operators and Regional Transmission Organizers to manage complex electric grids, largely owned by private companies. (Federal Energy Regulatory Commission, 2018)

Privacy and data security will continue to be a problem. But interesting behavioral issues are being revealed. Lyft and Uber, for example, collect enormous amounts of data about individuals but it appears the benefits of the service outweigh privacy concerns. (Shaheen, 2016)

1. Information to manage traffic and reduce congestion

Shared information can help manage use of roadways to minimize congestion, promote safety, and encourage efficient new mobility solutions. This can be done both by sending vehicles (including automated vehicles) detailed, real-time information about road conditions and augment signage with information about traffic signaling, speed limits, and construction diversions). The systems can be useful for the operation of individual vehicles and for system operators to optimize system-wide efficiency using curb management, usage fees, waiting and relocation strategies, lane reversal, vehicle prioritization and other mechanisms.

A significant amount of information is already available from sensors embedded in the current highway system. Over 60% of US freeways have traffic cameras and about half have real time data collection technologies in 2013. This is double the fraction in 2000 (Sheehan, 2015) An enormous amount of information is also generated by individual vehicles (which will become increasingly sophisticated as intelligent vehicle controls incorporate GPS, cameras, and LIDAR). In principle, this privately gathered information can be aggregated and integrated with a wide range of other sources (traffic cameras, satellite imagery, cell phone data, drones), to provide location-specific information to vehicles and to transportation system operators. Some information can be communicated directly from vehicle to vehicle. (v2v)

At present, however, proprietary communication systems are advancing far faster than public systems (e.g. OnStar by GM, Lexus Enform, Mercedes-Benz mbrace, and BMW Remote) (Shaheen, 2016). This runs the risk that the advantages of shared real-time information will be lost in a babble. The US Department of Transportation is aware of both the opportunity and the problems and has launched an extensive program to address it. (U.S. Department of Transportation-b, 2017) This includes supporting field testing such as the Mcity facility in Ann Arbor. (University of Michigan, MCity, 2017)

Some public systems for making better use of the large volume of data potentially available to manage traffic systems. Several European countries are developing a Service Interface for Real Time Information (SIRI), an XML protocol (Gruel, 2016) and many US cities are making creative use of the Google General Transit Feed Specification. (Google a, 2017) The Dutch have an aggressive program using 4G LTE, 5G/DSRC communications to provide vehicles data with less than 1 second latency using 4G/LTE claiming high security. They are testing applications that include (de Jonge, 2016):

- In vehicle signage and speed advice
- Individual real-time data on potentially dangerous situations and road works warnings
- Real time information for bikes and pedestrians
- Prioritizing (conditioned and general) of groups of road users at traffic lights
- Provide road users with real time data from traffic lights
- Optimizing traffic flow through traffic lights

- In-car parking data

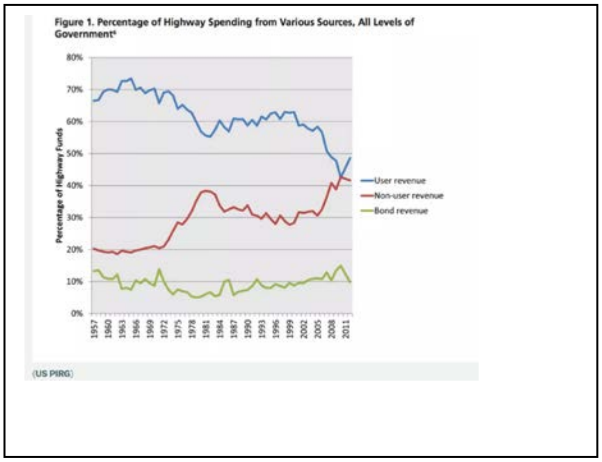
Apps and other tools that let users choose between alternative mobility services are highly dependent on reliable, timely information about guideway conditions, and vehicle locations. Systems like Google Maps Swiftly and Transit show users a range of options (drive alone, walk to a bus, ride a bike, Lyft, Uber) and some, like Transit, help users find shared bike rentals for a range of rental services. Ideal Public transit information apps are typically much less powerful and less well designed. All of these depend on scaping publicly available online data. Thanks to an early Google investment, transit and bus schedules are now published in a standardized, open format and now covers everything from horse-drawn carriages to helicopters. (Google a, 2017) An extension allows access to real-time data about vehicle positions where it's available. (Google b, 2017) This relies entirely on information voluntarily supplied and there's no guarantee that future mobility systems will participate.

Current systems typically compare price and travel time but an improved system would presumably expand to include time and cost associated with parking and the health and environmental benefits of and costs alternative trip types. Few existing systems show specialized services for children and people with disabilities.

The City of Dallas has developed an app that allows users to see options for both public systems and transportation networking companies. (Kaufman R. , 2015 a) In general, however, proprietary systems appear to have moved so rapidly that public systems are unlikely to compete even though the service that these apps provide a critical public service and are essential for encouraging innovative future mobility system.

2. Information for revenue collection

Future mobility systems will require innovation both in ways to pay for vehicles and ways to pay for the physical and information infrastructures. New payment systems are already urgently needed; user revenues for highways from gasoline taxes and other sources were about 70% in the 1960s but a reluctance to increase taxes means that they cover only 40% of costs in 2011 –see Figure 1 (Stromberg, 2016) And these costs are far below what is needed to maintain the quality of the highway system. Rapid introduction of electric vehicles will make the problem much worse.



Usage fees for highways and perhaps transfer points can be powerful tools for encouraging next generation mobility systems. They can build on current systems. The use of tolling systems, with fees adjusted by time of day and preferences for "high occupancy vehicles" are now widely used (Krol, 2016) (US Department of Transportation, Federal Highway Administratio, 2008). Some European cities charge a high fee for entering congested parts of the city and similar systems are being explored in the US. The California road charge pilot program is one example (California road charge pilot program, 2017) The New York State Congestion Mitigation Commission estimated that congestion pricing would have reduced VKT by 6 percent in midtown Manhattan and increased average speeds by 7 percent. (Bliss, 2017) Recent studies conclude that a "road use per mile" tax of 2-5 cents could decrease VKT by 20-40 percent. (Fox-Penner P. G., 2017)

Existing systems use a variety of transponders or "tags" in vehicles to determine vehicle position and traffic cameras to ensure compliance. Future systems can take advantage of the data generated by new mobility systems and a variety of other new data sources to tailor fees much more precisely based on traffic conditions and knowledge about the occupancy of individual vehicles. Clearly bus ridership is discouraged when, as is the case in large cities, buses with dozens of passengers travel slower than vehicles with a single occupant. (TransitCenter, 2016 a) Incentives would reverse if high occupancy vehicles had priority. "Traffic signal priority" systems are in widespread use in London and Los Angeles. An experiment in Brooklyn showed that giving buses signaling priority cut travel times on a busy section of Nostrand Avenue from 29 minutes to 22 minutes. (Nir, 2018)

One major barrier to the use of new mobility systems is the complexity of payments. Cash payments have all but disappeared (now only 11% of transit payments) but there is no standardized replacement. New systems which mix different travel modes (vans, bus, bike) would be greatly facilized by a seamless system of payments. The Netherlands and Finland have taken the lead in trying to design “door-to-door mobility service” using streamlined payment systems based on a standardized “smart card” to use a taxis, public transportation, and other services. These include Mobility Mixx, NS-Business Card and Radiuz Total Mobility.

3. New sources of transportation data

All of these new systems depend critically on accurate and timely data on travel patterns. For decades, transportation data has come largely from government sponsored surveys (Transportation, 2017). New technologies have made it possible to gain access to government data formerly sequestered in government repositories. The New York Taxi and Limousine Commission released a large volume of data (TLC trip data, 2017) and the City of Chicago has made available transportation data available in an elegantly designed website (Chicago Transit Authority, 2017). The University of Michigan Transportation Research Institute is engaged in building a sophisticated tool that will greatly expand access to transportation data (Center for data-Intensive Transportaton Research, 2017).

Available data, while extremely valuable, lacks critically important information on the trips people actually make, which may involve walking or riding a bike to a bus stop and then walking to an office (multi-modal origin-destination data). Reported driving time seldom reports time spent searching for parking.

Federally funded programs are enriching traditional sources of transportation data using a range of new technologies. These include the University of Michigan's Safety Pilot program organized by UMTRI – where over 2,800 private cars were equipped with GPS antennas and Dedicated Short Range Communication (DSRC) devices (University of Michigan Transportation Research Institute, n.d.) – and the University of Maryland's (I-95 Corridor Coalition Vehicle Probe Project, n.d.)

Box 4
Modernize traffic data.
Develop and implement robust data-sharing requirements for new vehicle technology to improve the quantity and quality of data collected, and to reduce the millions of dollars spent annually on technologically primitive data collection, both from regular traffic operation and from traffic crashes. Traffic management will remain a function managed or regulated by the public sector even in a future dominated by private mobility providers. Public policies should foster open data platforms that enable robust private innovation to better serve transportation customer needs, while reducing aggregate social and environmental costs and inequities through a regulated utility model framework.

National Association of City Transportation Officials 2016 (NACTO, 2016)

New technologies provide orders of magnitude improvements to traditional data both in volume and timeliness. The new generation of Transportation Network Companies such as Uber and Lyft collect extensive trip data. Cell phones (which report the user's location to the local cell tower) and built in GPS location devices can provide extremely detailed information on a large fraction of all travelers and do so in near-real time. Proprietary data systems such as OnStar and Navistar collect travel information from the vehicles that carry them. New vehicle to vehicle and vehicle to infrastructure systems communicate location data and even the early driver-assist automation in current vehicles have the potential to capture data for individual vehicles. Fully automated vehicles, equipped with cameras, LIDAR, and other sensors can capture extensive real-time data about road and traffic conditions. These sources, of course, only collect mobility information for people in cars, completely missing walking and biking. Bike share companies, however, are gaining market share and can collect detailed origin-destination and other trip data. The next section will discuss at length the challenge of understanding trips not taken because of a disability or poverty. Almost all of this data, of course, is proprietary and seldom available to government organizations. They all share a common defect in that they do not collect travel data on people who don't own smart phones or own new-model vehicles or travel using transportation network companies.

The gap between the quantity and quality of public and privately owned transportation is growing rapidly triggering concern by public agencies. There is concern both about access to the data and the lack of uniformity in which the data is gathered (American Public Transportation Association, 2016). There is also a growing gap between public and private capacity to analyze this data. (Tsay, 2016) Virtually all efforts to gain access to new transportation data have failed (Vaccaro, 2016) (Brownstone, 2016) An effort by the City of Boston to gain access to Uber data in exchange for allowing Uber to operate in the city did not generate anything close to the data quality that was expected. (Vaccaro, 2016) Cities clearly have the power to be more aggressive in the future. The TransitCenter observes that "private transportation companies rely on publicly funded road infrastructure to support their businesses. It is reasonable, then, for public agencies to expect something in return, especially if it would lead to improved transportation planning. (TransitCenter , 2016 b) New York City has been particularly aggressive adopting a new regulation requiring that Transportation Network Companies share their data with the city-- including data on pickup, drop-off, trip duration information. (Woods, 2017)
A variety of private businesses have grown up to assemble and provide analytical tools for the new sources of transportation data – for a fee of course. These include:

- **Inrix** which"provides transportation and planning agencies with accurate and affordable trip data, allowing them to track trends " (Inrix, 2017)
- **Streelight** "origin-destination studies and more" (data, 2017)
- **Teralytics** "We work with leading telecom companies and data partners around the globe to capture information about people's geographical locations, movement habits and demographics; all completely anonymized and aggregated." (teralytics, 2017)
- **Air sage** " trip matrix specific attributes include: origin & destinations, day part segmentation, resident/visitor classification, trip purpose, external/internal, long distance trip filters, home/work classification, demographics" (airsage, 2017)

4. Analytic Tools

The research priorities described earlier present a daunting set of challenges for data science. The volumes of data are vast, they come from an enormous variety of sources in a variety of formats and ownership restrictions. Real-time systems require very fast response times – and there will be a need to find designs that a compromise between precision and timeliness doesn't decrease safety. They must be able to operate under conditions of incomplete and missing data but remain extremely reliable since lives are literally at stake. The systems must be highly secure and resistant to accidents and malicious hacking. They must manage large volumes of financial information securely and manage large amounts of personal data without violating privacy assurances. The information must be presented to system designers, vehicle operators and system operators in a way that facilitates decision-making. And the system itself must be designed to monitor overall performance and drive continuous improvement. It is also critical to find ways to reduce bias in multifactor analysis (Yang E. B., 2015) and ensure that fairness criteria are established and met. (Salem M. A., 2016)

In many cases analysis cannot rely on data from carefully designed experiments and must rely on highly unconventional data sources such as social media, news articles. These heterogeneous sources must be combined with more conventional data sources.

In all cases, the analysis risks bias in the underlying data that can disadvantage groups which may not be well covered.

Fortunately, advances in causal inference, statistical machine learning, causal inference, signal processing, and data mining are directly relevant to these problems – though considerable work needs to be undertaken to realize their potential. For example,

- Optimization methods allow the design of highly sophisticated "seamless mobility" systems based on hub and spoke models (Maheo, 2017)
- Tools for controlling intersections (Xie X. S., 2002) (Cassandros, 2015)
- Automated planning and scheduling (Xie X. S., 2012) (Xie X. S.)
- Multimodal factor analysis can be used to reduce bias in use of heterogeneous data including unconventional sources. (Yang E. B., 2014) (Yilmaz, 2015)
- Methods for ensuring fairness (Salem M. A., 2010) (Joseph, 2016)

- Exploring use of “multi-armed bandit” methods (Auer, 2002)

Unmet demand for travel

What we know about existing travel patterns may not be a good guide to the future. The dramatic changes possible in the US land transportation system during the coming decades will introduce options that could sharply reduce costs and travel time, and increase accessibility. This, in turn, will change transportation markets in ways that are now poorly understood.

There are two compelling reasons to improve this understanding: 1) forecasting future demand for travel – needed to anticipate impacts on environmental quality, congestion, and other metrics and, 2) understanding how well the new technologies will affect people underserved by the existing transportation systems.

There are two linked effects. The first is the well-known phenomena of “induced demand” where lowered costs increase demand for travel as people make trips that would not have been taken at a higher price. Forecasts are typically based on a “price elasticity” computed from historic data. (Leard, 2016) (Duranton, 2009) The second involves travel that may be induced by the dramatic changes in both cost and convenience of new mobility systems that may tap deeply into previously unserved populations – particularly low income and disabled groups.

1. Induced Demand

Elasticity data relies on historic data to predict the impact of changes in price on transportation behavior. The revolutionary changes in mobility underway, however, could impact vehicle travel in unique ways. (Kockelman, 2017)

- A shift from individual to business owned vehicles could change the perceived cost of traveling (a personally owed car owner may only consider the fuel cost per km while a commercial vehicle would charge the fully weighted cost (capital, O&M, insurance, licensing, and fuel) per km.
- Increased vehicle occupancy if the cost of shared vehicles can be dramatically decreased while the speed and convenience is dramatically increased.

- Electric vehicles may lead to shorter trips because of “range anxiety” but may also increase driving because of the need to find charging facilities
- Automated vehicles may reduce vehicle km traveled by eliminating the need for parking1 but may increase km traveled if they lead to increased sprawl or frivolous use (send a vehicle home in lieu of parking). They could also facilitate platooning that could allow more vehicles to travel without increasing congestion.
- There could be rapid growth in specialized transportation services driving up km traveled – in an “Uber for everything” market. There are already businesses for delivering laundry, massage, flowers, and doctor visits (Fowler, 2015)
- Improved urban design could see walking and biking substitute for many trips now taken exclusively by car (new mobility options are likely to shape urban design decisions).
- Telecommuting and increased use of on-line shopping could reduce travel demand.(Shaheen, 2018)

2. Underserved Populations

It is important to understand whether new mobility systems will lead to significant improvements in the mobility of underserved populations. In an economy designed almost entirely for automobile travel, Americans unable to drive for reasons of disability or income face enormous barriers. Access to jobs, health care, groceries, after-school programs, depends on reliable access to affordable education. It’s estimated, for example, that 3.6 million people fail to get needed medical care because of “transportation problems”. (Wallace, Access to Health Care and Nonemergency Medical Transportation: Two Missing Links, 2015) Car ownership in the US is the best predictor of upward social mobility. (Chetty R. H., 2015) (Chetty R. H., 2014) (Danziger, 1998) (Wallace, Access to health care and nonemergency medical transportation: two missing links, 2005) (Cronk, 2015)

Lack of car ownership is a severe impediment to employment since only about a quarter of low and middle skill industries in large metropolitan areas can be reached in less than 90 minutes by transit. (US Department of Transportation) A long commute may even be a barrier to getting a

[1] Driving in search of parking may reach 20-30% in extremely congested downtown areas but it appears that parking searches are responsible for 5-6% of vmt in the whole of Sanfrancisco and 3-4% in Ann Arbor. (Weinberger, 2016)

job since hiring firms recognize that long commutes increases the risk of attrition “the longer the commute, the lower their recommendation score” (Stocker, 2016)

6.1 million Americans have a visual impairment that prevents them from driving. (Lutin, 2016) The Department of Transportation reports that “Half of Americans over the age of 65 report having some form of disability, and one in three reported having trouble getting the transportation that they need”. (US Department of Transportation). Losing the ability to drive is a severe blow. Most older people feel a direct connection between driving and their independence, well-being, and ability to maintain social networks. This often leads to accelerated decline in health. (AAA Foundation for Traffic Safety, 2015)

Lacking access to cars, low income individuals make heavy use of other mobility options. People earning less than $30,000 per year were responsible for 17 percent of all trips in 2009 but they made 26 percent of local transit trips, 60 percent of trips using transit for people with disabilities, 27 percent of bicycle trips, and 28 percent of all walking trips. And even though they often lived in areas where the streets are unsafe, they accounted for “virtually all” of trips which involved walking some distance to transit pickup points. (Twaddell, 2016) A well-designed “walkable” community can contribute to good health. Obesity is strongly correlated with the lack of walkability. (Go Boston 2030 Mayoral Advisory Committee, 2017)

Some low income people are now turning to transportation network companies like Uber and Lyft when they can afford them. While roughly a third of low income households don’t have a smartphone (Anderson, 2017), a recent study by the Public Transportation Associated that lack of access to technology was not a major barrier. The fraction of low income people use transportation network companies is roughly the same rate as that of upper income groups (a much lower fraction travel by car). When asked what they would do if the transportation network service wasn’t available, most upper income people said that they’d drive while most lower income people said that they simply wouldn’t take the trip. (American Public Transportation Association, 2016)

Efforts to subsidize transportation for people underserved through paratransit are largely unsatisfactory. They often require days of advanced planning and are costly. The average paratransit trip costs the MBTA $49.53 and the average utilization of each paratransit vehicle is 1.49 passengers. (A Better City, 2015) One obvious solution would be to subsidize transportation network firms to provide these services but contracting faces significant barriers since strict standards are required for any company receiving federal funds – drug/alcohol testing, strong liability coverage, access to wheelchair and service animals, domestic manufacture, and others). Some specialized firms are beginning to provide trained drivers for services such as SilverRide for older adults and Shuddle and HopSkipDrive which provide services for children. (American Public Transportation Association, 2016)

Behavioral Issues

The success of new mobility systems, particularly those that involve shifting from individual vehicle ownership, depends in crucial ways on behavioral issues. Behavioral science has developed sophisticated new tools for understanding how decisions are affected by the combination of rational analysis and other factors, (Thaler, 2008) New machine learning and other methods have the potential to greatly improve our ability to use data in implementing these theories. (Wang, 2015) (Chen C. M., 2016) But much remains unknown.

A key question is whether it will be possible to the change the high level of US dependence on automobiles. Behavioral changes are clearly underway but the data is murky. There has been a steady decline in the number of 16-44 year olds who have a driver's license. 92% of people in this age range had licenses in 1983 but this fell to 77% in 2014. On the other hand the percentage of people over 70 with a license increased from 55% to 79% over the same period (Sivak, 2016) The fraction of households that do not own a car is increasing slowly (8.85% to 8.97% between 2010 and 1016. Single person-households were least likely to own a car (nearly 19%). (Census)

But the stubborn fact remains that 86 percent of US workers commute by automobile, and ¾ of them drive alone. While young millennials in urban areas may be experimenting with new mobility systems, they don't appear to have changed their commuting habits. Young people living in urban areas use cars less frequently, but 77% of them still commuted to work by car. Some large cities are chainging more rapidly. Automobile commuting declined 3.8 percent in

Greater San Francisco between 2006 and 2013, and 3.3% in Boston. (Florida, 2015) (McKenzie, 2015)

Transportation Network Companies are actually adding to urban congestion as more vehicles enter urban space, many empty, looking for rides. The hours spent by conventional taxis and the new transportation network companies spent driving in Manhattan nearly doubled between 2013 and 2017. (Schaller, Empty Seats, Full Streets, 2017) While the new transportation companies often offer ride sharing options, the fraction of trips involving multiple passengers remains very low. Affluent customers are least likely to purchase shared rides. Only 10% of rides in Manhattan were shared while citywide, 18% of Lyft and 12% of Uber trips were shared. Chicago and San Francisco did somewhat better (17% of Lyft and 26% of Uber trips were shared). The added vehicles appear to more than offsets the congestion mitigation gains realized by ride sharing presenting a major policy challenge. (Schaller, How to put the pool into Uber, 2018) Car-pooling rates have actually declined (McKenzie, 2015)

The lack of convenient alternatives to driving, and urban designs built around the assumption that mobility would be provided solely by cars, are clearly part of the problem. Non-car alternatives are particularly limited for people with small children or people who travel at non-peak hours. But there are deeper behavioral issues at work. Even successful transitions to new transportation systems can take years to achieve. (LEK/Commission for Integrated Transport, 2002 quoted in (Redman L. F., 2013)) The fate of new mobility systems depends on identifying barriers to using new mobility systems, and the kinds of incentives, pricing, features, nudges, and other actions that can encourage use of the new markets.

The factors that influence decisions to use different mobility systems remain poorly understood. Some data suggest that the trip speed, low waiting times, and reliability are more important than fares and easily accessed information. (Redman L. F., 2013) (Wall, 2007) In a recent survey, only 27% of drivers who had shifted travel modes said that cost was the primary reason. Only 27 percent of drivers who have switched sectors report income was the primary reason for switching. (TransitCenter , 2016 b) Another survey found that only16% of transit riders were there to save money; 40% had no alternative (e.g. couldn't afford a car) and 44% were riding because they preferred it to driving. (Clark, 2017)

On-demand ride-hailing services are rapidly increasing their share of trips, particularly by young, affluent residents of large cities. 21% of adults in “major cities” use ride hailing services and nearly a quarter of these users use the service on a weekly or daily basis. They gave a number of reasons for using these services but the top reason was difficulty finding parking (37%). Avoiding driving when drinking was also high on the list (33%). (Clewlow, 2017)

There is a striking correlation between income and transit preference. Colledge-educated, upper income Americans use ride-hailing services twice as frequently as people with lower incomes and were less educated. Younger people use ride-hailing services at eight times the rate as people over the age of 65 (Clewlow, 2017) About half of people with incomes below $50K preferentially took a public bus and 20% took a public train. The pattern was reversed for people with incomes greater than $100K (20% and 40%) (Murphy, 2016) This is undoubtedly due in part to higher property values associated with attractive public transportation choices. Modern “bus rapid transit” systems may change this. (Sadik-Khan, 2016)

Other research suggests that information about the availability of transportation alternatives – particularly new mobility modes -- is very important. The failures of shared mobility program in Kansas City and the failure of the micro-transit company Bridj are apparently at least partially the result of an inadequate program to inform the public (Marshall, 2017). There is some evidence, however, that the great improvements in information available from apps that provide real time information can have a significant effect – even making people realize that new mobility systems may be preferable to driving (Shaheen, 2016) . These recommender tools also carry risks since if users are ever given inaccurate information, they may simply stop using them. (Dievorst, 2015)

Box 3
Getting to and from Public Transit

More than two-thirds of transit users (69%) walk to their stop or station. Another 11% drive to their stop, while 10% indicate that they use another form of transit. The balance are either dropped off (6%) or use another mode.

On alighting from their transit vehicles, most transit passengers walk to their destination (76%). Another 16% transfer to another transit vehicle, while 4% drive, 3% get a ride, and 1% could not be classified except as “other.

half of the trips made (50%) require a transfer

(Clark, 2017)

The “first and last mile” is obviously a major factor. A large fraction of all public transportation riders walk to and from their ride (see Box 3). A shared mobility system that could move people efficiently to a transit node seems likely to make a dramatic difference in ridership. Comfortable transfer facilities with clear information signs and minimal wait times should also provide powerful incentives.

An experiment that followed a number of individuals who volunteered to give up their car for a week found a variety of advantages to new mobility systems that they’d never considered. Among them was the discovery that they could continue their use to social media apps while traveling (Shaheen, 2016)

Another challenge may be finding ways to get individuals to feel comfortable in multi-passenger vehicles. A recent UC Davis pooling and pricing workshop concluded that “American’s simply don’t like to travel with strangers” (UC Davis, Institute for Transportation Studies, 2016) Transportation Networking companies have tried to allay these concerns using recommender systems in their apps that can provide a level of trust on the part of both drivers and passengers

Studies of existing experiments face the obvious limitation that existing services only provide a fraction of the services (including timeliness, reliability, comfort) that seamless mobility systems should be able to provide. Since powerful seamless systems can be built quickly and relatively inexpensively with known equipment, significant experiments should be possible in the near future.

Even given a deep understanding of how to create markets for new mobility systems, and the availability of attractive new systems, changing deeply ingrained habits can be a challenge. Recent research suggests that it will be key to focus on a few opinion leaders who can influence the behavior of many others. (Budak, 2012) Social networks, presumably also reflecting opinion leaders, can also have a powerful influence on behavior. (Oselio, 2014)

Several programs have been attempted:

- The Central Ohio Transit Authority will offer free bus rides for a week to get riders familiar with it's redesigned route network. The new system is designed so that. an additional 110,000 jobs will be within a quarter-mile of regular bus service. (Knox, 2017)
- A project that encouraged 6,281 people to use carshare programs in the U.S. and Canada found that "25% of members sold a vehicle due to carsharing, and another 25% postponed a vehicle purchase." Their VMT was reduced 27-43% (Martin and Shaheen 2011)
- A variety of games, rankings, and rewards have been tried in programs attempting to get people to use non-car transportation options. A recent survey showed that 23% of the transportation apps used "some form of gamified incentives such as savings, raffles, or favicons (a special badge denoting level of achievement. Rider incentives for ongoing behaviors can include discounts, coupons, gift cards, and other rewards." (Shaheen, 2016)
- Health Apps, and the motivational communities built around them, can encourage transportation modes like walking and biking. They can also be a critical part of an information program showing users the health implications of mobility choices. These tools can also provide advice about safe biking and pedestrian strategies.
- Environment/Energy Consumption Apps that track environmental impacts and energy consumption of travel behavior, for example greenhouse gas (GHG) emissions associated with different modal choices. (Shaheen, 2016)

While user behavior is key, there are also a number of behavioral issues associated with drivers employed in the variety of new occupations created by new mobility systems. Transportation Mobility Companies find that they often have trouble keeping drivers on call at the right time and at the right places. (Chen M. S., 2015). Financial and non-financial incentives and game-like motivational approaches have been tried, with mixed success. (Scheiber, 2017) (Salanova, 2011) The new mobility systems will have a major impact on employment. Most of the jobs are currently vehicle operators and maintenance personnel – jobs that have comparatively low barriers to entry. Training is typically provided and pay is generous. The new mobility systems will generate a range of new employment opportunities but obviously the introduction of automation would be a threat to lower skilled workers. Total employment could be sharply reduced for unskilled workers. The transition may be facilitated by the fact that existing transit workers have the highest percentage of their workforce over the age of 55 (35% vs US average of 22%) and many can retire before the age of 55. (US Department of Transportation, Federal Transit Administration, 2016) Retirements, of course, don't address the question of job opportunities faced by workers that will need to find other employment opportunities.

Next Steps

The stakes are high for public decisions that will guide the next generation of mobility systems. The consequences for the quality of mobility services, the businesses that supply them, the people that work for transportation companies and their suppliers, and the environment are very large. The forces driving a real revolution cannot be resisted but they can be guided. The earlier discussion shows that enormous uncertainties remain about the possibilities and their potential benefits and liabilities. Given the consequences and the speed of change, governments at all levels must begin to develop the clearest possible understanding of the options and begin to design clear strategies and begin a dialogue that will ensure that changes are welcomed and supported by the broadest possible constituency. Hard decisions will be needed about urban design, public transportation, electric utility policy, data accessibility, and support for low income and disabled travelers. It will clearly be necessary to understand the options and their consequences with as much clarity as possible. Among other things, this will require rethinking research priorities – some of the key questions are listed in the Appendix. But the time to start is now.

Appendix

Research Priorities for Next Generation Mobility Services

1. Urban Design and Physical Infrastructure

New mobility options create a wide range of opportunities for reinventing existing transportation business models and introducing some that are entirely new. The challenge, of course, is the enormous range of possibilities. Both public and private investors will need to create a range of tools for simulating future markets and for operating highly complex, fast paced systems spread over large geographic areas. Policy makers will require tools for evaluating new regulatory requirements, new revenue models, on all segments of the population, economic impacts including distributional impacts, and impacts on energy use and the environment. Key tools will include:

- Methods for predicting potential usage of different mobility systems that can be used to estimate needed physical infrastructure investment – including transfer points.
- Methods for optimizing the size and operation of fleets that minimize travel time and costs and maximize convenience
- Methods for collecting and synthesizing large, heterogeneous sources of data on travel and road conditions and making it rapidly available to users in a standardized format.
- Methods for optimizing real-time routing of vehicle fleets either owned by public transportation systems or under contract with them. These will include large, multi-passenger vehicles and smaller "on-demand" vehicles.
- Methods for ensuring that travelers lacking access to smart phone service are still well served
- Tools for designing fee structures that best match vehicles and customers and efficiently matches riders with vehicles. Can game-theoretic methods or other methods be useful?
- Ensuring that designs and operations of new mobility systems can accommodate the needs of children and people with disabilities.
- Methods for optimizing movement of vehicles that are not publicly owned using road usage fees, traffic signaling, and other mechanisms.

- Design of fee systems that reduce or eliminate increases in travel induced by lower prices and autonomous vehicles (e.g. sprawl) while ensuring mobility for underserved populations.
- Methods for estimating willingness to pay for different quality of services. Methods for ensuring that mobility is affordable and available to all citizens.
- Methods for simultaneously optimizing the efficiency of mobility systems and electric utility systems to maximize services and minimize costs.
- Methods for combining heterogenous payment systems into systems that are seamless to the user but allow payments to competitive providers
- Methods for anticipating future ridership needs (day ahead, week ahead) based on deep learning analysis of mobility patterns influenced by weather, special events, and other factors.
- How can new mobility systems best serve different urban designs from high to low density
- How will the three revolutions affect land use and real estate prices
- What design steps can be taken to encourage attractive shared mobility and other advanced systems (zoning, road and walkway design, transfer point infrastructure)
- What policies are needed to encourage optimum vehicle charging infrastructure? What role should utilities or public institutions play.
- Effective integration of walking, biking, and new vehicle systems
- Tools for training new employees and continuously updating their skills

2. Information Infrastructure

Since traditional sources of data are unlikely to provide a good picture of many of the changes underway, it will be necessary to aggregate "non-design" samples including social media, news media and possibly new sensor data to fill the gap. What new sources of data can be tapped to understand the way new transportation systems are being used? How can the heterogeneous data be combined into a useful multifactor analysis

- What can be learned about unmet demand from existing surveys and "non-design" samples? What new sources might be mined (hospital and clinic data, social services, grocery sales)
- What international data sources are available that might shed light on uses of new mobility systems?
- Can useful simulations be built to anticipate the range of potential outcomes reflecting the uncertainties?
- What travel behavior and trip choice modeling techniques apply to new populations of riders? What factors will influence their decision to shift modes?
- What new forecasting and technology adoption forecasting methods will apply to new mobility systems
- What kinds of data are needed to design and operate modern mobility systems (presumably covering: all modes, all demographics including income and disability, origin destination, trip purpose, passengers per vehicle, speed and congestion)
- What mechanisms can be developed for providing public access to critical mobility data generated by public agencies?
- What mechanisms can be used to encourage or require data sharing?
- Can tools be developed to facilitate the integration of large volumes of heterogeneous data produced at high velocities?
- Could data standards make this task easier?
- What mechanisms could be employed to better track non-vehicle trips (bike and pedestrian)

3. Behavioral Research

- What features are most likely to attract users to the range of new mobility systems ? Do these factors vary with demographics, parental status, disability?
- What are the biggest barriers to shifting from traditional car usage to the new mobility systems?
- What incentives (or disincentives) are most effective in getting significant numbers of individuals to try new mobility systems and continue using them?
- What incentives are most likely to encourage walking and biking? What would be the net impact of increased non-vehicle travel?

- What is the optimum way to motivate drivers for transportation network companies and services?
- Can deep learning systems develop a predictive model of consumer preferences based on heterogeneous data
- How can Transportation Network Companies (and public equivalents) make improve decisions drivers make about where and when to drive? How can their decisions be changed with new incentives?
- What will be the workforce implications of new mobility systems. What kinds of training and other programs could help maintain employment opportunities?

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