Smart Mobility: Challenges and opportunities for the next generation of transportation

Transportation is an essential component of living in smart cities, but what would mobility in smart cities look like? This article is an overview of the opportunities and challenges presented by smart mobility.

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In 2020, American households spent $1.2 trillion on transportation, making it the fourth-largest spending category after healthcare, housing, and food [1]. An average American is estimated to have spent about 286.7 hours traveling in 2020, or about 438 hours in 2019 [2]. People use transportation systems to access better employment or education opportunities, get medical care, for recreational purposes, to obtain daily goods, or to meet friends and family. Another major aspect of transportation networks is moving freight. Freight transportation affords many benefits by moving raw materials, intermediate goods, and finished products from where they are in abundance/produced to places where there is demand. The vital role played by transportation can be seen both directly and indirectly. In the United States alone, direct impacts include economic value associated with the jobs (14.8 million jobs in 2019) and fixed assets ($8.3 trillion in 2018) associated directly with transportation [3]. Examples of indirect impacts are the economic activity spurred through the availability of transportation ($19 trillion worth goods moved using U.S. transportation networks in 2017 [4]) and societal benefits such as access to better jobs. Hence, the importance of transportation in everybody's lives seems self-evident.

Where transportation provides tremendous benefits, it also poses several challenges. Some of the challenges are obvious such as pollution (22% of CO_2 emissions in 2019) and safety (40,732 deaths in 2020 [5]). Other challenges are not so obvious such as equitable access, where equity may be limited due to income, race, or disabilities. These challenges provide opportunities for academics, the public

sector, and the private sector to create solutions and direct change that will impact billions of lives.

There is a lot of interest in smart transportation from self-driving cars to drones performing Amazon deliveries. More recently the passing of the "Infrastructure Investment and Jobs Act" last November provides approximately $1.2 trillion of funding to improve electric, internet, and transportation infrastructure with a significant portion of the spending allocated toward making safe policy and constructing infrastructure for the next generation of transportation enabling smart cities in the U.S.

SMART MOBILITY

Smart mobility is the portmanteau used to refer to transportation in the context of smart cities. To have a good understanding of what smart mobility is, we need to take a closer look at what smart and mobility mean. "Smart" is an adjective that has gained increasing use to describe complex systems of the future. Broadly, a smart system is a technology-driven system that interacts with end-users and/or other smart systems. It uses some combination of hardware (e.g., sensors) and software (e.g., signal processing, machine learning) to accomplish its intelligent behavior. How those interactions happen, and their effects, are something that changes with the availability of technology. But specifically in the context of cities, what it means to be smart has changed over time. Earlier, smart cities were just communities that were using a nifty gadget in an existing ecosystem. However, more recently, the idea of a smart city is about developing and using technology with a specific outcome in mind. The key here is the development of technology. In earlier cycles, the technology was developed independently, and then applications for them were identified in the wild. Now there is a push to identify end goals first, and then develop technologies to accomplish those goals. Better transportation is one of those goals that we hope to achieve through technology.

We must ensure everybody has access to safe, convenient, cheap, and reliable transportation. This is all enabled by technology.

Transportation has its roots in Latin words *transportare*, which literally translates to carry across. Contemporary use of transportation is related primarily to moving people and goods. Currently, this movement is accomplished through modes powered by humans or animals, air transport, land transport, water transport, pipelines, or even space transport to name a few. Each mode of transportation has its own requirements for fixed infrastructure, operation, and maintenance and by using a different technological solution it provides different and very specific benefits. For example, a remote mountainous area may be inaccessible to land or water transport and may require a helicopter or drone to meet local needs. While we want to develop technology that accomplishes our goal of improving transportation, it is worthwhile to reflect on what improved transportation might look like. Consider that due to the differences in required resources for each mode of transportation and constraints supplied by the society served by a transportation system, different modes of transportation may be optimal for different communities. This leads to differences in cost, accessibility (due to availability), safety, and reliability of use. This then leads to the idea that any future transportation solution must not only enable the movement of goods and people but also be able to do so while being cost-effective, equitable, safe, reliable/resilient, and sustainable. Although these guiding principles are enough if we consider transportation in the traditional context, we may want to consider some other principles as technology becomes more ubiquitous. Privacy is an example of such an additional consideration as city transport systems become smarter. Another example is making resilient systems not just safe for one in 50-year floods but secure from cyberattacks.

To reflect the complexity of what an advanced (and smart) transportation system should do, the term mobility is often used over transportation. Although the two terms sound similar, there is a slight difference in what they refer to. Transportation itself is simple in that it is the ability to

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move goods or people, and mobility is the ability to access multiple modes of transportation while having a reasonable quality of score in the guiding principles outlined earlier. So while good transportation is a binary question of whether we can move goods or people, good mobility is a continuous scale of how well we can move goods or people. And therefore, the future of advanced, technology-enabled transportation is smart mobility. Smart mobility is when we use technology to not just improve the modes of transportation themselves, but also use technology to improve the factors affecting their quality and availability. Pursuing smart mobility, as is the case with most things, has trade-offs. Both opportunities and challenges manifest in the pursuit of this goal.

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UNLOCKING OPPORTUNITIES

Since smart mobility exists in a symbiotic relationship with physical, and increasingly digital, infrastructure, we can group the opportunities provided by smart mobility based on the stages of life within an infrastructure system. A typical infrastructure life cycle broadly consists of four stages: planning, building, operation, and end of life. Let us explore some of these opportunities through examples.

Planning stage. This stage in the infrastructure life cycle is roughly associated with assessing needs, feasibility, impact assessment, and solution identification. For example, if it were possible to pinpoint the routes traveled by vehicles traversing the existing network, it would be possible to figure out the exact demand for passenger travel. We can then plan for links to add to the current transportation network to accommodate transportation demands. This can replace current traffic travel pattern studies that make several assumptions that may not hold true over time. This can be especially useful in freight infrastructure planning. By understanding the freight weight, volume, and value demand, we can locate the best facilities for collaborative use. This could be especially important if we wanted to include newer methods of urban freight delivery such as drones, self-pickup hubs, crowd workers, or sidewalk robots. These types of methods are hyper-local in terms of coverage areas and would need optimally located facilities to provide reasonable coverage and economic advantage.

Let us look at another example for using smart technologies in the planning phase of transportation systems. Current highway design follows a one size fits all approach by using the "Manual on Uniform Traffic Control Devices for Streets and Highways," which provides guidance for every aspect of roadway design, including setting speed limits [6]. On the one hand, where this provides certainty to local officials and planners in terms of highway design, not having enough flexibility for local context makes the roads more dangerous. In this case, the speed limit is set by performing a speed survey of motorists using the road and setting the speed limit to the 85th percentile of the results. This results in very high-speed limits for arterial roads leading to most of the fatalities involving car crashes. It also biases the system toward fast-moving motorists who can revise the speed upward through the years by going faster [6].

Smart technologies can help in this case through two means: incorporating local contexts while setting the speed limit and having dynamic speed limits. Even preserving the existing rule-based nature of designing roads, computer systems can enable storing and applying a higher number of more contextually aware rules while also making the design process faster. In addition, speed limits can be made to be dynamic such as lowering them due to pedestrian use of roads during the day and possibly increasing them at night.

Construction stage. Beyond the obvious benefits of using robots, like autonomous bulldozers to perform the construction tasks to finish construction faster [7], there are other benefits that smart technologies can provide during this stage of the infrastructure life cycle. A recurring example of construction impacting everyday users are the closures that are associated with construction. Road, sidewalk, or parking closures are not impromptu and are typically planned-out weeks or even months in advance. In a smart city, it would be possible to encode these closures during the permitting process itself. Hence when motorists, pedestrians, and bikers (or even delivery robots) are using the built infrastructure, they can plan routes that avoid going through shut-off areas.

Use stage. This stage of an infrastructure system is the one most people interact with. There are opportunities afforded by smart technologies in this stage that don't just help users use the system better, but also help with maintaining the infrastructure. An example of this is using optical fiber cables embedded in highways to detect potholes and traffic characteristics like congestion in real-time. This is accomplished using distributed acoustic sensing and has been in use to monitor sensitive installations for a long time [8]. Combined with advanced roadway material technology, such as self-healing pavements [9, 10], the infrastructure repairs proactively rather than reactively. Smart technology can also similarly enable proactive monitoring for other pieces of infrastructure, such as bridges, using autonomous drones [11].

Communication between different participants in the transportation system can be enabled by utilizing smart technologies. The ability to communicate brings about a host of benefits. Communication between infrastructure and users can enable more flexible use of infrastructure by better informing users. A case in point is static curb signage, which can get complicated in bigger cities. Confusing signage can be simplified by only displaying what is active at a given point of time directly to the user through proximity. It would also make it easier to set up notification alerts such as parking time limits. This would avoid scenarios where cars get towed, which could cost an average of $557 in San Francisco [12] where these types of costs disproportionately affect lower-income people [13]. It also enables congestion and usage control policies such as dynamic availability and pricing parking spots.

Communication between infrastructure and users could also inform users about future road conditions so that there is more time to plan. Future road conditions may also be communicated through user-to-user interaction. In self-driving technology, this can lead to a network effect in the efficacy of the autonomous systems, where you have current road information before your camera or LiDAR system even sees anything. Through infrastructure-to-infrastructure communication, we may be able to set up green light corridors or open alternate paths to combat congestion in real-time.

Smart technology can also help increase mobility itself by allowing people to use multiple modes of transport more conveniently. Consider Mobility as a Service (MaaS), which posits that we can plan, pay for, and use intercity or intra-city travel with one application. A MaaS app can be a true door-to-door travel application. Instead of needing to check multiple apps [14], everything happens through one app. Another example is technology enabling precise turn-by-turn navigation, which would benefit people who are blind to better interact with a city's transportation network through voice-based navigation. As a bonus, by modifying the system to also give directions through a screen rather than voice, others can also better navigate the city.

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THE CHALLENGES OF A SMART MOBILITY SYSTEM

Smart mobility has a lot of potential to improve the quality of transportation available to users, however like most things it is not a panacea. There exist trade-offs and difficulties in the pursuit of smart mobility. While a particular smart mobility solution may help alleviate one shortcoming of the transportation system, it may introduce challenges based on multiple guiding principles outlined earlier (economic, equitable, safe, reliable/resilient, sustainable, and privacy preserving).

An example of a broader challenge is the requirement for sensors everywhere. This requirement creates challenges on multiple fronts. The first challenge is the increased amount of electricity that sensors would require. To manufacture sensors, there would be a higher number of raw materials needed. Both electricity and raw material requirements may lead to higher economic and/or environmental costs. From a networking perspective, creating and maintaining a massive network of sensors is a big engineering challenge. Other engineering challenges include processing and storing the volume of data created. There are also requirements for privacy and security. Highly networked systems present additional challenges from the perspective of cybersecurity. Privacy becomes an issue since devices that are used for providing a seamless or otherwise better service could also be used for surveillance, persecution, and harassment.

Another challenge that could hinder mobility gains is access to the internet and cashless payment methods such as credit cards. Several current proposals for advancing smart mobility, such as MaaS, would require people to own a smartphone with an internet connection. Programs such as tap-to-ride require a linked credit card, but 5% of the U.S. adult population do not use a bank instead they use alternative financial services [15]. Most households that were unbanked had a family income of less than $25,000, while Black and Hispanic households without banking services reported higher numbers as well. This is important to note because these are groups who may be more at risk of having low mobility in the first place [16]. This is an issue of equitable access.

The development of smart mobility systems should be done with the diversity of users in mind. This is especially important since the development of these systems are currently underway. There exist examples of leaving large proportions of the population out while developing the next generation of transportation. For example, as a result of excluding women while developing car safety standards, it puts women at a 47% higher risk of severe injuries compared to men, if they're involved in similar crashes [17].

Issues of access are also exemplified by reducing access to fixed infrastructure. Consider autonomous cars, for example, it has been shown that under certain conditions, autonomous vehicles may prefer to cruise on roads rather than park [18]. This reduces access to roads for users wanting to travel. Or consider autonomous sidewalk robots for deliveries, if robots are using sidewalks, it may reduce access for pedestrians including wheelchair users. Although smart mobility may increase access, there might be challenges in making sure accessibility is improved for everybody.

Drones have been touted as the next generation of last-mile movers of people and goods for a while. But one of the reasons they have not been adopted yet is noise pollution. This is an example of an externality not covered under one of the guiding principles. Although drones are getting quieter, we're not there yet. Ultimately, innovators in this space need to realize that technology exists to support a community and improve the quality of life. And technological advancements must go toward that improvement. Public policy can go a long way in ensuring that technology works for the people. However, creating a policy for something that does not yet exist is a hard problem. Policy is essentially a people problem and working with multiple people with competing goals who may or may not be wary of the future is a challenge in itself.

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CONCLUSION

Smart mobility is the future of tech-enabled transportation. In an ideal future, regardless of the mode of transport, self-driving cars, or teleportation devices, we must ensure everybody has access to safe, convenient, cheap, and reliable transportation. This is all enabled by technology. We've explored some examples showcasing how smart mobility expands opportunities. We've then seen some challenges that present themselves for the adoption of smart mobility as well as challenges that could arise from adopting smart mobility. Transportation is an essential service and really should be treated as a utility. Although there are challenges, there are many ingenious solutions that already exist and are in further development.

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Biography

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