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Autonomous Vehicles: Rethinking Traffic Congestion Solutions in Cities

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Abstract

Autonomous vehicles (AVs) will be the next technological leap for urban mobility. The question for decision makers and city leaders is whether they contribute to achieving progressive social, environmental, and economic targets or achieve the opposite. AVs offer benefits such as safety, convenience, and enhanced mobility for the young, the elderly, and the disabled. However, AVs themselves will not relieve traffic congestion and in fact could exacerbate traffic and increase vehicle miles traveled (VMT) unless clear regulations and policies are adopted to manage their use. In this paper, we outline the four transport planning tools that are used to relieve traffic congestion: (1) land use measures, (2) transportation demand management, (3) transportation system management, and (4) road widening/new roads. We address how AVs will complement or disrupt the effective use of these tools and conclude that the tools must be overhauled with the advent of automated mobility. Policy recommendations are provided for each tool. In addition, we briefly discuss the new safety challenges posed by integrating AVs into traffic.

Keywords: Autonomous Vehicles; Transportation Demand Management; Transportation System Management; Sprawl

1. Introduction

Land use and transportation are inseparably linked. Throughout history, any advancement in transportation technology has had major impacts on travel patterns and urban form. Following the advent of the automobile in cities where policies did not intervene, higher speed and more efficient vehicles brought urban sprawl. Residents began to live far from city centers and drive farther to work. Although car-oriented cities benefited a portion of their populations, they created adverse economic, environmental, and social impacts for the majority.

Mainstream car manufacturers already boast of semiautonomous driving technology built into some high-end vehicles. Level 5 autonomous vehicles (AVs), which can operate in mixed traffic scenarios, are being tested in several locations throughout the world. Many urban developments and road layouts are already lagging in addressing the changes that AVs will bring. Their use will reshape cities, and it is imperative that decision makers also overhaul policies to ensure that we maximize the efficiencies of this technology.

A revolution in urban mobility will revolutionize a city's future development. Girardet [1], co-founder of the World Future Council, raised the concept of two opposing city types. First, the dystopian "Petropolis," a geographically spread-out city that relies on fossil fuels, has a high urban metabolism and large ecological footprint. Second, the utopian "Ecopolis," a compact, "regenerative" city based on a circular economy with a smaller geographic and ecological footprint. A Petropolis with high urban sprawl is less efficient not only because of the greater distances traveled in vehicles, but also because of the greater energy used to transport water, wastewater, and other commodities. It is taken as fundamental in this paper that mobility of the future should be a catalyst to transform cities away from the traffic congestion, fossil fuel dependence, air pollution, and urban sprawl associated with a Petropolis.

Within the emerging field of automated mobility, a battle of ideas has arisen between those developing private AVs (self-driving cars, typically from automobile manufacturers) and those advocating nonmotorized and public transit modes. This paper focuses on how the unregulated advance of private AVs will affect the four tools that are commonly used to combat congestion and briefly discusses the new safety challenges posed by integrating AVs into traffic. It concludes by describing how these strategies must adapt to ensure that the future state of cities is liveable and sustainable.

2. Impact of Transportation Technology Advancement on Urban Form

Transportation has been the framework upon which cities are formed. Land use and transportation are interconnected: change in one influences change in the other. In his notable book, *The Ways of the World*, Maxwell Lay [2] provides a history of the evolution of transportation technology from the earliest footpaths to the rise of wheeled vehicles and animals to pull them, the development of surfaced roads, the motivation behind building roads and bridges, and the advent of cars and their impact on roads, cities, and society in general. Lay highlights three distinct eras: ancient times, the Industrial Revolution (ca. 1825–1900) and the private motor vehicle era (1925–present). Each era is distinguished by a different transportation technology and a correspondingly different urban form.

In ancient times, the main modes of transportation were by foot or animal. As a result, land uses were centralized for better accessibility and connectivity. The Industrial Revolution brought higher speed streetcars, subways, elevated rail, and commuter rail lines that replaced the horse-drawn cars and enabled residents to live farther from urban centers and thus reduced population densities while main land use activities centered on transit stations. Finally, the private motor vehicle era spread land use activities beyond the walking distance to transit stops or stations. From 1916 to 1920, automobile ownership increased from 2 million to 8 million; by the beginning of World War II (1940), the United States alone had 32.45 million motor vehicles. After World War II, the U.S. Federal-Aid Highway Act of 1956 authorized the construction of 41,000 miles of high-speed freeways and expressways. By 1972, these roads would connect 90 percent of the cities with a population of 50,000 or more. They were also built to link many smaller cities, which resulted in the development of low-density suburbs that could only be served by cars. Urban areas expanded and encroached on agricultural areas far beyond city limits [3]. Most European cities had road layouts that were based on transportation by foot or animal and thus struggled to cope with the advent of cars.

In general, any advancement in transportation technology that led to higher speed resulted in a separation of land use activities and changed settlement arrangements. Urban sprawl resulted in higher vehicle miles traveled (VMT) and greater traffic congestion, which, in turn, resulted in more pollution and greater energy consumption and cost. Cities became less transit oriented and less walkable to such an extent that they even harmed the health and well-being of the population they supported. AVs are also expected to significantly affect the shaping of the physical, social, and economic gradients of cities. Below we describe why and how the four tools to address traffic congestion must adapt to AVs.

3. Four Tools to Alleviate Traffic Congestion

To alleviate traffic congestion, urban municipalities commonly use four tool categories:

- Tool 1: Apply land use measures for mixed-use, compact, and high-density development. Such land use measures are effective because traffic is the manifestation of land use, thus they target the cause of traffic.
- Tool 2: Implement transportation demand management (TDM) to shift modes from private automobiles to public transit and high-occupancy vehicles (HOV).
- Tool 3: Implement transportation system management (TSM) to optimize the current arrangement and manage traffic more efficiently.
- Tool 4: Widen roadways and add new roads and parking. These measures attempt to ease traffic congestion by managing the supply side of transportation and extending physical infrastructure.

4. AV Impact on Tool 1: Improve Traffic by Applying Land Use Measures

Travel is a derived demand; trips are generated as a result of land use activities. The most effective tools to alleviate traffic congestion are those that address the causes rather than the effects. Mobility within a city must satisfy various trip purposes, but the distance at which mobility is required can be reduced. Land use measures, including mixed-use, compact, and high-density developments, make such reduction possible. These measures bring origins closer to destinations and thus reduce the VMT. A risk is that the convenience provided by AVs will increase the distance that passengers are willing to travel, which conflicts with the goal of compact and high-density development.

The Arizona Department of Transportation [4] conducted extensive research on the relationship between higher density development and traffic congestion. The research also refers to a variety of studies that indicate that higher density developments result in ownership of fewer cars and in households that drive less, walk more, and take more trips on public transit. On average, the daily VMT generated by households for higher density developments is one-half to one-third of the daily VMT of their suburban counterparts. The study also concluded that travel behavior is affected by land use factors such as mixed-use development, automobile versus pedestrian-oriented design, and regional accessibility enhanced by multiple travel choices (especially transit); these factors are effective in improving traffic. These characteristics—density, diversity, design, and destination—are known as the 4Ds. The travel market that may be most influenced by compact mixed-land use is nonwork travel. Real estate industry experts state that more compact, mixed-use development has not occurred because of restrictive local zoning codes or traffic level of service standards rather than because of market demand. Visual preference surveys indicate a general preference for older (pre-World War II) suburban development patterns: these developments are more compact and walkable, and they foster more social interaction among residents. In addition to improved mobility, compact cities consume less water and energy than do sprawling Ecopolis-model cities.

In many cities, rules and regulations have not been amended to address congestion, and the higher speed and greater efficiency of cars has encouraged populations to live in low-density suburbs away from activity centers, which has resulted in urban sprawl. AVs will also bring higher speed (due to less delay in traffic flow as the result of steady flow of platooning vehicles), but more importantly, the convenience of AVs will enable travelers to drive longer distances in a high level of comfort, and they can work or rest in the vehicle. This will encourage residents to live farther from urban centers and will encourage developments to grow horizontally, which will decrease accessibility to public transit, increase infrastructure requirements, and reduce farmland and natural areas. Policies and regulations must be enacted to curtail the negative impacts of AV on urban form.

5. AV Impact on Tool 2: Improve Traffic by Implementing Transportation Demand Management

TDM is a series of measures that emphasizes the mobility of people and goods rather than cars and includes measures to promote walking, cycling, ridesharing, public transit, and telecommuting. TDM's effectiveness depends on the availability of modes other than single occupant vehicles (SOVs) and policies to encourage their use. To estimate mode shares, discrete mode choice models traditionally use the observed modal attributes of alternatives (e.g., travel time and cost), and characteristics of commuter sociodemographic (e.g., household income and number of drivers in a household). These models have not paid much attention to the unobserved attributes, such as the effect of convenience and comfort on choosing a mode of transportation.

Mode choice models in transport planning should be improved by considering the often-ignored location-specific and latent variables in addition to the conventional ones. A study conducted by Alex et al. [5] identified five latent variables: (1) mode comfort and convenience, (2) commuter habits, (3) mode safety, (4) commuter life cycle, and (5) mode reliability. Johansson et al. [6] have proven that mode choice decisions also depend on commuters' preferences for convenience, safety, or flexibility. In several examples, a "latent variables enriched" model outperforms a traditional model and offers insight into the importance of these latent variables in mode choice. In general, the results confirm that time and cost are significant for mode choice, but they also indicate that preferences for flexibility and comfort are very important.

One of the main objectives of the automotive industry in the advent of automation is to increase sales by focusing on enhanced comfort and convenience for travelers. AVs will allow travelers to work—and rest—while traveling. AVs can remove the inconvenience associated with searching for parking spaces. Moreover, AVs serve those who cannot drive, such as the young, the elderly, or the disabled. In choosing AVs over other modes of transportation, the importance of convenience and comfort are location specific and will vary among socioeconomic groups, but in many studies, comfort and convenience were listed as the prime factor in mode choice. These criteria play an important role in determining the mode choice and encourage the use of private AV modes rather than public transit. The result will adversely affect future traffic unless authorities make policy decisions to prioritize societal interest over individuals. Cities have witnessed the same effect from automobiles. Although private automobiles have enhanced individual comfort and convenience, in the absence of best practice planning and smart growth measures, they have negatively affected the quality of life and, in many urban areas, they have prioritized the automobile above the people they are meant to serve.

AVs will provide mobility for those who cannot drive (e.g., the young, the elderly, and the disabled), thus generating new roadway demands. This segment of demand currently uses modes other than SOVs; as a result, the VMT relating to this segment of demand will rise. On the positive side, public AVs will promote car sharing for regular travel, especially for commuting, thus reducing overall car ownership and vehicle travel, especially in compact urban areas. Carlo Ratti, Director of MIT's Senseable City Lab, predicts that vehicle automation will require 80 percent fewer cars on any given highway. He states, "In general, fewer cars could mean shorter travel times, less congestion, and smaller environmental impact," but he also warns of nightmarish scenarios. If private AVs were to become significantly cheaper than public transit, cities could easily become gridlocked [7]. This echoes the earlier observation that policies and legislation must grow at the same rate as technology to ensure that we are not prisoners of the AV era and that we do not lose the ability to influence the modal shift to public mass transit options.

6. AV Impact on Tool 3: Improve Traffic by Implementing Transportation System Management

TSM relates to the measures that optimize existing infrastructure performance by preserving capacity and improving the security, safety, and reliability of the transportation system. Many intelligent transportation system solutions are part of TSM programs. AVs will optimize the use of existing roads and intersections by shortening gaps between cars, coordinating platoons, and employing more efficient route choices. However, cities may experience drawbacks when cars are left on their own to look for parking after they drop off their passengers. It is a well-known fact that a significant portion of traffic congestion in densely populated urban areas is caused by drivers looking for parking spaces. Because AVs have no need to find a parking space, this inconvenience and its resulting congestion will be reduced or eliminated in some areas. However, AVs will have to be sent to various destinations without any passengers. As the legendary urban designer Peter Calthorpe states, "the only thing worse than a single occupant vehicle (SOV) is a zero occupant vehicle (ZOV)" [8].

Another focus of TSM is optimizing incident clearance. Statistics reveal that driver error is the primary cause for all crashes [9]. Car accidents are not only a tragic safety issue; they also cause traffic congestion. Although confidence will take time to grow, with proper systems assurance and oversight, AVs will reduce—and eventually eliminate—human error and thus improve traffic safety. The congestion associated with accidents will diminish accordingly.

7. AV Impact on Tool 4: Improve Traffic by Widening Roadways and Adding New Roads and Parking

Conventional traffic engineering mistakenly treated roadway networks as conduits or pipelines, looking at them merely from the standpoint of supply and demand analysis without considering human factors. Since the 1950s, cities have given high priority to cars and roads rather than to people. Traffic congestion has increased, and walkable urban spaces have been compromised; the wider streets developed for cars are now considered unsafe and unappealing by pedestrians.

The "tragedy of commons" is an economic theory describing how individuals tend to act selfishly by depleting publicly accessible and underpriced or free resources, eventually degrading the public realm in terms of environment, energy consumption, health, and well-being. The theory is usually applied to the effects of pollution in public spaces, but the same principle can be seen in the way cars use public space. Travelers will continue to use and congest roads unless planning and policies—coupled with suitable design and land use measures—discourage private automobiles and provide incentives for public transit. A key question is whether AVs will result in more new and wider roads and parking spaces or whether they will result in the opposite.

The sizes and locations of parking facilities are expected to change significantly with the advent of AVs. Although a reduction in car ownership will decrease the need for parking facilities such as residential parking, park-and-ride sites, and shopping center parking, AVs will increase the need for dropoff spaces. Parking spaces for AV rentals may also increase in places such as public transit terminals and train stations [10].

Some studies and current projects advocate the segregation of AVs from human-operated vehicles. Dedicated guideways entail a wider right-of-way, wider curb radii at intersections, and potentially the provision of crash barriers, underpasses, or bridges. By widening roadways, segregation can compromise the walkability of a city. Typically, a pedestrian-friendly city will have few barriers, a narrower right-of-way, tighter corner radii at intersections to lower motorists' speed and a shared street system that allows different modes of transportation to coexist. However, at higher speeds, the need to build confidence in the safety of AVs remains a significant challenge before society allows a complete mixing of AVs with other vehicles on all roads. In the future, the need for segregated guideways will diminish, thus improving efficiency through the shared use of road infrastructure.

8. New Safety Challenges

Transportation systems face many new challenges in accommodating AVs. This paper focuses on the traffic demand and supply aspects of AVs; however, the impacts of AVs on safety, security, cost, energy consumption, pollution, privacy, and equity are also important. AVs could have both positive and negative effects on traffic and mobility. For example, AVs will enable many segments of the population (e.g., the elderly, the disabled, and those too young to drive) to become more mobile, which increases the number of people travelling and thus increases congestion.

AVs could greatly affect traffic safety. Todd Litman [11] comments that although AV optimists claim that 90 percent of crashes in the United States are attributable to human error and that accidents will decline overall, such claims overlook the fact that the convenience of AVs will put more vehicles on the road, and the added congestion is likely to increase accident rates. New safety risks will arise, such as hardware and software failures, malicious cyberattacks, or physical attacks on AVs for amusement, to test the system, or to prey on vulnerable people. AVs will provide greater mobility for the disabled, elderly, and younger passengers, enabling their greater inclusion in society, but they also present technical and safety challenges that must be addressed.

As confidence in AVs grows, passenger risk taking may also increase. AV passengers may use commuting time to eat, sleep, or exercise; as a result, they might cease to wear seatbelts. Pedestrians may use less caution walking in front of an AV than they would for a self-driven vehicle. During the early stages of AV deployment when self-driving vehicle are mixed with AVs, some drivers may attempt to join the platoons of AVs that may be operating on dedicated lanes close together at high speeds, which would result in increased crash severity. Furthermore, AVs have not been sufficiently tested in inclement weather (e.g., snow or heavy rain).

With the advent of AVs, the safety and security of both normal and vulnerable road users and pedestrians are challenges to be addressed. These issues will require further research followed by a rigorous and comprehensive approach to system assurance throughout the life cycle of AV development, testing, and operation. When system assurance is undertaken, the process should be broad enough to address the entire AV "ecosystem"; that is, the vehicles as well as all supporting and interfacing infrastructure that constitute the operating environment.

A key policy recommendation is for city leaders to quickly incorporate current efforts into the legal guidelines, specifications, rules, and safety regulations that are being developed for AVs worldwide.

9. Conclusion

Safety challenges notwithstanding, this paper focuses on how the four tools to relieve congestion must be revised to accommodate automated mobility. The following is a proposal for the key policy recommendations for each tool:

- Policy Recommendations for Tool 1: Land Use Measures
  1. *Ensure that compact, mixed-use developments (origins close to destinations) are preferred over spread-out, low-density city models to avoid the negative impact of widespread high usage of private AVs.*
  2. *Provide detailed policies to protect a city's urban growth boundary or green belt.*

- Policy Recommendations for Tool 2: TDM
  1. *Promote safe, high-quality public (shared) AV options to enable a modal shift away from SOVs or ZOVs.*
  2. *Provide subsidies for traveling in public AVs and provide disincentives for private AVs to move more people in a limited space.*

- Policy Recommendations for Tool 3: TSM
  1. *Develop AV safety regulations to enable AVs to coexist and integrate with normal traffic rather than limiting them to a specific guideway.*
  2. *Invest in connected traffic systems to ensure that AVs (a) navigate urban roads safely, (b) avoid traffic congestion, and (c) provide a bias for higher occupancy vehicles.*
  3. *Develop AVs in a manner that ensures they reduce and eventually avoid reliance on fossil fuels by integrating the latest electric vehicle and vehicle-to-grid smart energy storage systems.*

- Policy Recommendations for Tool 4: Road Widening/New Roads
  1. *Review all proposed road schemes in relation to AVs and the modal shift potential of public AVs.*
  2. *Review parking requirement standards in the light of the alternative requirements of AVs.*
  3. *Allocate space for strategically located AV charging and maintenance facilities.*
  4. *Design low-speed urban areas for the coexistence of AVs and pedestrians.*

With the advent of the automobile in the 20th century, some cities developed regulations and policies that resulted in positive impacts; others suffered. Such differences are reflected in the plans developed for New York by Robert Moses; in contrast was the position taken by the activist Jane Jacobs. Moses' decisions involved building highways and moving away from public transit, which resulted in urban sprawl and the far-flung suburbs of Long Island. However, Jane Jacobs organized grassroots efforts to protect neighborhoods from "slum clearance" — in particular, Moses' plans to overhaul Jacobs' own Greenwich Village neighborhood [12]. Moses' plan for the Lower Manhattan Expressway would have decimated the neighborhoods of SoHo and Little Italy; Jacobs was instrumental in the project's eventual cancellation. These neighborhoods experienced a renaissance in subsequent years.

Moses was a proponent of the early 20th-century vision that the only salvation of cities was the large-scale destruction of their existing features; Jacobs maintained that the future of cities rested on preserving those features. Jacobs' book, *The Death and Life of Great American Cities*, was a powerful rebuttal to Moses' mode of thinking, and her actions provided a convincing argument against his mode of operating [13].

Such dichotomies could also arise with the advent of automation in the 21st century; some cities may follow the Petropolis model to the detriment of their citizens and the planet as whole; while others will move toward the Ecopolis model. "Autonomous" should not be synonymous with "smart." If the substance of any action is smart, automation will make the system smarter. However, if the overall framework is not efficient, automation will exacerbate the inefficiencies. In conclusion, the challenge for municipalities and city leaders is to implement policy recommendations that bypass conventional transportation planning thinking to ensure that the advantages of AVs outweigh their potential disadvantages.

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