Autonomous Cities and the Urbanism of the 4th Machine Age: Should AV Industry Design Future Cities?

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Abstract. The on-going revolution of autonomous vehicles (AV) has great implication on the car industry; after years of stagnation, a new wave of innovation stimulates a global discussion about future mobility. But despite the inherent relationship between cars and their urban surroundings, cities are hesitant to embrace or even thoroughly discuss the change. Although industry leaders promise penetration of AVs into global markets within less than a decade, little discussion has been offered and only few guidelines and long-term plans were released in regards to the relationship between AVs and the urban surroundings or supporting infrastructure. Given the rapid pace of technological advancement and the inevitable tardiness of urban-scale planning and execution, this paper asks to divert the discourse form focusing on AVs and their technologies to the city and its infrastructure. By emphasizing the relationship between AVs and their immediate urban surroundings, this work suggests that a 'results driven' planning approach is necessary for successful adaptation of this innovative technology. It offers several precedence of cities that chosen to focus on the quality of their urban surrounding than to surrender to cars-oriented design.

Keywords: autonomy, cities, vehicles, streets, architecture, urbanism, urban planning, urban design, wellbeing, sustainability

1 Introduction

The promise of autonomous vehicles and the gradual shift towards on-demand urban transit are all leading to a deep paradigm shift in the way cities accommodate mobility. In many ways, this change has already begun: recently, after decades of domination, private car ownership went down for the first time in the history of the US; Urban rebirth and 'back to the city' movements are defying suburbia; trucks, cars and bicycle-sharing platforms changing the way people move in cities. While these trends are projected to increase in the coming years, contemporary cities are focused primarily on patching holes in old mobility solutions or proposing incremental changes to existing infrastructure. As of today, little research has been done on a broad and compressive vision for the relationship between autonomy and the city.

The importance of such debate is tied to the pace by which new mobility technologies are announced and marketed. Both academic and non-academic publishing is seeing an ever growing coverage on all angles of this subject. Despite the growing interest in this subject, predictions concerning the rate and depth of AVs adaptation are varying dramatically. Certain assumptions conclude that market-ready AVs would become a common commodity within less than 5 years. Others are more skeptical and attaching 'trend' and 'science fiction' jargon when regarding AVs, comparing it to 'moon colonies' and other technological promises that evaporated after their exposure and popularity have declined.[1]

However, both industry leaders, government officials, policy-makers and large percentages of the public agree that this change is coming. Even the most pessimistic assumptions do recognize future incorporation of this technology and are mostly skeptical about its adaptation rate and prominence over other major transportation shifts. In a recent study done by IHS Automotive, more than 54 million self-driving cars will be on the road by 2035; by 2050, every car on the roads will be autonomous.[2] The AV market is predicted to grow to $42 billion by 2025 and to reach $77 billion by 2035, with 25% AVs of all cars.[3]; In the course of the next 10 years, the US government promises to invest $4 billion AV research.[4] It is hard to imagine that these unprecedented investments could be dismissed as yet another technological promise or a temporal 'hype'.

2 Background

Unlike many other technological progressions of the last decades, AVs are unique by their inherent relationship with their 'accommodating' infrastructure. This infrastructure will continue on serving AVs, the same way it has served cars and carriages in past centuries. These physical and tangible solutions were all conceived, designed and constructed in reaction to transportation trends of their times and are mirroring the way humans and goods movement was perceived by modern and pre-modern city planning.

Despite being controlled by robotic or computational systems, AVs should act no different in respect to urban infrastructure - they will consume paved roads, parking spaces and most other types of urban infrastructure in different capacities. Even if mass proliferation of AVs is not projected to happen in the immediate future, it is indisputable that when a critical mass of AVs will rule urban transpiration, cities and their greater urban context will endure major tactile implications. These will ultimately have direct and indirect impact on the design of buildings, streets and neighborhoods as well as the on the directions of new infrastructure investments.

Yet currently, the relationship between AVs and their corresponding infrastructure is one sided. The pace by which comprehensive changes are being carried to cities is

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[1] http://www.gartner.com/newsroom/id/3114217

[2] http://www.planetizen.com/node/66723

[3] https://www.bcgperspectives.com/content/articles/automotive-consumer-insight-revolution-drivers-seat-road-autonomous-vehicles/

[4] http://techcrunch.com/2016/01/14/us-government-plans-to-invest-4b-into-autonomous-driving-research-over-the-next-10-years/

no match to the rapid advancement of AV technology. In fact, all AV being developed by major industry are trained and tested to withstand current state of urban infrastructure and to respond to the current challenges as human drivers.

The hurdles stalling cities from adapting these large scale changes could be learned from the turn of the century 'connected city' revolution. These technologies, such as gas pipes, telephone wires and advanced sewage systems [3], emerged within western cities during a short period at the end of the 19^{th} century. The cities inability to quickly adapt to these changes resulted with undocumented and disorganized installations of many of these systems, causing costly technical issues for years to come.

2.1 Regulations and Policies

Most current regulation and on-going regulatory processes are designed to provide safety umbrella for the development, testing and marketing of AVs. For that reason, these regulations mostly cover safety and security aspects but have no implications to infrastructure design. The NHTSA regulations and state who permit AV testing provide room for car companies, developers and market forces to compete on market shares without superimposing or restricting particular products. These efforts are necessary in order to control unrestrained industry from endangering users or other vehicles and to ensure quality of products.

2.2 The Free Market Perspective

The sensitive and fragile relationships between the authorities need to control and the wish for free and unrestrained markets is not new. While regulatory bodies aim not to utilize their domain to manipulate the free market, they still responsible for keeping the public well-being and safety. An unaccounted shift in this delicate balance can result in a public turmoil, when consumers sense their liberties were unrightfully apprehended. Defining the boundaries between acceptable restraining of the market and suffocating regulations is a complicated task which could bare economic and political consequences or even threaten democracy.

In the US, regulators are divided in terms of AVs. Currently, there are only few states in which AVs are fully permitted to be tested, but even there there are great uncertainties in regards to what and how they will be regulated when fleets of AVs will swarm the cities. The fragile liberty granted to AVs development is mostly founded on legal gray zones more than it is consciously defined in the eyes of the law. Most lawmakers act as bystander amidst the many uncertainties: which technologies will prevail, when will they fully penetrate the market, how consumers will respond; effectively, market leaders and technology early-adopters are the ones setting the tone in this discussion. [4]

2.3 Autonomous Vehicles and Urbanism

While some discussion is already taking place in regards to AVs and public safety, nearly no discourse has been offered in respect to implications on urban planning and city design. Most major US metropolitans are not including these changes in their future plans and limited number of research papers and design projects envision the effects of AVs on city planning.

AVs advocates commonly correlate these technologies with immediate remedies for many of the drawbacks associated with modern transportation and urban planning. For them, the advantages of AVs are not strictly limited to the sheer performance and safety of the vehicles but also to other respective fields, such as logistical challenges, city planning, environmental concerns, wellbeing and more. But effectively, early assessments and predictive models often show different or sometimes negative results. As such, current research predicts contradicting evaluations in regards to MVT, road congestion or parking utilization.

Overtime, it becomes apparent that assessing the implications of AVs using existing prediction models, especially in regards to physical and tactile aspects, is a complex and imprecise effort. As Childress et al declared: "impacts of autonomous vehicles are highly speculative. Future impacts depend on technological development, market reactions, and regulatory actions, making it challenging to confidently predict impacts to regional transportation systems. With so many unknown and potential effects of AVs, it is challenging to anticipate long-term effects with certainty. However, some of these impacts should be considered early on… to develop feasible analysis boundaries. With these analyses, agencies can prepare more dynamic long-range plans..." [2]

2.4 Envisioning Autonomous Vehicles

As shown, the relationship between cars and the tangible aspects of their accommodating cities were deeply-rooted during the last century. Different modes of urban transportation emerged corresponding typologies and when vehicles were banned, these typologies adopted walkability and biking features. The upcoming shift towards driverless vehicles is anticipated to once again reshuffle the relationship between city form and its means of transportation.

A slowly-growing body of research is trying to predict the implications of autonomous shared or privately owned fleets of vehicles on the city. Many of these researchers are building local or regional models that are simulating the behavior of different AVs fleets through supply and demand, effects on road-congestion, air-pollution and environment, parking demands and more. However, most of these assessments take into consideration similar infrastructures and cityscapes as they exist today; In other words – despite some simulations predict complete driverless cities, filled with nothing but robotic cars, the streets, the buildings, the sidewalks and parking are all assumed to stay the same. This approach could be explained by the growing gap between time-consuming infrastructural modifications and rapid technological advancements: while the industry promises market-ready products within few years, city plans are projecting two or more decades ahead.

But even when assuming that AVs will reside within the same urban scenarios, there are great uncertainties about how, when and to what degree they'll be incorporated. Attempts to model AVs effects face lack the necessary evidence to be built into travel demand models: “Because these vehicles do not yet exist but modelers need to incorporate their possible impacts on travel demand, the most straightforward way to understand behavior would be to conduct a stated preference survey… Travel models will need to have major improvements in the coming years, especially with regard to shared-ride, taxi modes, and the effect of multitasking opportunities, to better anticipate the arrival of this technology.” [2]

The outcomes of this ‘predict and provide’[5] approach bring transportation officials and planners to project infrastructure investments sometimes four decades in advance. By doing so, their ability to intervene and react to current disruptions - such as AVs, ridesharing or energy crises - is nearly impossible. As soon as long term projects have been approved and financed, it is particularly difficult to reverse the planning. A recent publication by the NLC put numbers to this phenomena: examining 68 transportation plans from 50 of the most populous metropolitans in the US, only 6% (California, Washington, D.C., Florida, Michigan, and Nevada) include AV and driverless technologies in their documents. The rest, despite projecting 10 to 40 years ahead, have no reference to AVs.

2.5 Planning the Unknown

How could cities do prepare for this seemingly inevitable change, giving that different predictions offer inconsistent forecasts? This paper aims to highlight how AVs might impact cities, in particular in relations to their tactile, infrastructural and physical elements. Given the complexity of comprehensively assessing these impacts in advance, this work aim to distill the eco-system and framework that are more likely to be affected by this change. It proposes a result-driven view of the extents affected by the change, and offers simplified matrices to assess the impact of AVs. Ultimately, it proposes a modified decision-making process, in which these understandings could serve policy-makers and the general public, in an effort to infuse conscious decision making for the future of autonomous cities.

3 Urban Autonomy

"Forget the damned motor car and build cities for lovers and friends."- Lewis Mumford, 1955

The relationships between modern types of mobility and their impacts on cities was broadly studied and explored. ‘Car culture’, Car-dependent urban-planning and ‘car-architecture’ led to massive changes in urban form, design of cities and neighborhoods and the architecture of buildings. The car gutted buildings and streets, shuffled land-use and redefined the design of landscapes.

[5] http://www.brookings.edu/research/papers/2015/04/17-driving-in-the-21st-century-dutzik-tomer-baxandall-puentes

3.1 Cars and the City

But similar to AVs, the sheer influence of the cars was initially slow. Building roads to facilitate the "removal of horses from cities was widely considered a proper object for the expenditure of public funds. Indeed, the private car was initially regarded as the very salvation of the city, a clean and efficient alternative to the old-fashioned, manure-befouled, odoriferous, space-intensive horse… This effort was so successful that… the private car had become no longer a luxury, but a necessity of the American middle class."[6]

Car-oriented city planning ruled the better half of the 20th century. In the city of Los-Angeles, 14% of the county's incorporated land (around 200 sq/mi) are dedicated to car parks, on-street parking spots and off-street garages and lots. In the urbanized area there are 16 acres of parking for every 100 acres of land, more than double the 7 acres of parking coverage from 1950 [1].

After nearly a century of suburbanization and sprawl, it is evident that the surrender to the car, its industry and marketing efforts is pivotal in the impetus behind the design of cites. In the twentieth century, one billion cars have been manufactured; currently, 1.2 billion cars are roaming the world and expected to become 2 Billion by 2035. The misconception of the car in urban studies is described by Sheller: "...cars have been conceived of either as a neutral technology, permitting social patterns of life that would happen anyway, or as a fiendish interloper that destroyed earlier patterns of urban life. Urban studies have omitted to consider how the car reconfigures urban life, involving… distinct ways of dwelling, travelling and socializing in, and through, an auto-mobilized time-space." [5]

3.2 Machine Restraining Mechanisms

The implications of cars on 20th century cities and infrastructure were dramatic, but not always irreversible. All through the century[7], cities, towns or other settlements elected to avoid cars, reduce traffic or alter it into alternative modes of transportation. These local governments decided to pursue a different path in respect to urban mobility and the design their infrastructure, and were able to harness their domain to persuade their local communities. Commonly independent, self-sustaining and with centralized planning apparatuses, these cities not only changed the landscape of mobility, but also constructed successful methods of community engagement, decision making and communication that cultivated their initiatives.

A city of Evanston, Illinois, with 75,000 inhabitants was designed as a suburb north of Chicago. In 1986, a new plan for Evanston embraced the idea of a '24/7' downtown, pouring resources into increasing its density and revitalizing its businesses. Along with the assembly of segregated parcels for high-density development, the city invested in reinforcing its public and regional transportation systems. Evanston's built a new downtown transportation center, and offered relaxed zoning restrictions

[6] https://en.wikipedia.org/wiki/Crabgrass_Frontier
[7] Car free places https://en.wikipedia.org/wiki/List_of_car-free_places

along two designated corridors to permit increased density of residential use. This type of mixed development, also known as TOD (Transportation Oriented Development) became a common two-fold for many neighborhoods across the US. TODs are coupling infrastructural investments and residential development to provide good transit solution within walkable distance and reduce the need for parking infrastructure.

One of the Evanston initial challenges were the city's own zoning regulations and their emphasis on car-dependent urban design. Evanston's old zoning ordinances called for 1.25 parking spaces per studio apartment, 1.5 spots for a two-bedroom apartment, and two spots for a three-bedroom unit.[8] Evanston's effort to amend its zoning and to abandon its old parking restrictions led to a drop in private car-ownership: In 2009, ownership of one car or none within half a mile of Evanston's downtown was 80% and 47% for all of Evanston.[9]

4 Ecosystem of Future Autonomous Cities

As shown, the pace of technological advancement is continuously surpassing most urban-scale adaptation processes. For that reason, when planners and designers project to a possible future, they must generalize the impacts of a particular technology. This could be done by extracting only the relevant features of an anticipated technological transformation and utilizing them to construct a framework for design. As an example, a team working in the 1960's on the design of a new bridge could not predict exactly what types of vehicles, at what capacity and for which purpose will use it 6 decades later. However, their design assumed certain parameters of future mobility and channeled them into their decision-making and calculations. Together with their local policy makers, these features where converted into regulations (i.e. - Bridge not to be crossed by certain type of vehicle, at a certain weight, height or during certain hours of the day) that mitigated the tangible aspects of the infrastructural project with their view on how the city should function. These features were not a representation of any specific vehicle but families and groups of characterizing features to could be employed regardless of the specificities of contemporary mobility.

Similarly, planning and urban design for AVs could not currently anticipate how this technology will change or infiltrate the global market. As shown, most current predictions share great uncertainty about the change and their numbers vary consequently. Instead, planners should consider AVs as ‘black boxes’: unspecified elements that only some of their features are apparent and relevant for present-day decision making. As such, the many different characteristics of AVs should be redacted to the minimum necessary for planners and urban designer to envision city plans for years to come. At this point of time and with the limited knowledge and practice offered regarding AVs, the features which bare most implication to the surrounding city

8 http://www.cityofevanston.org/planning-zoning/downtown-zoning/

9 http://www.politico.com/magazine/story/2015/10/evanston-illinois-what-works-213282

and infrastructure are related to (1) the degree of automation, and attached to (2) the question of private versus shared ownership.

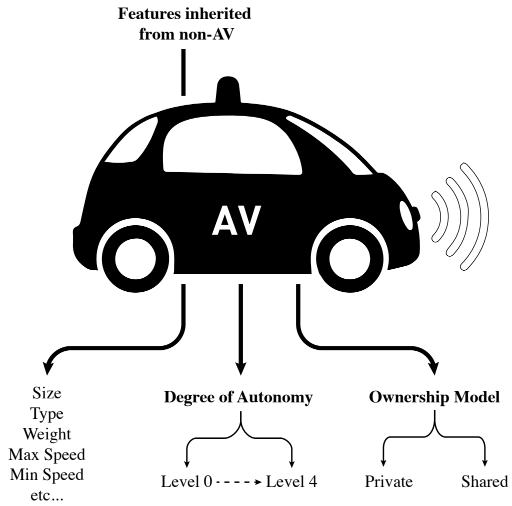

Fig. 1. AVs inherited and added features

4.1 Different Degrees of Autonomy

A growing number of car manufacturers are currently offering different degrees of automation in their new or refined car models. These features are often described as Advanced Driver Assistance Systems, or ADAS. This table presents existing and upcoming ADAS systems for several leading manufacturers:

Maker	ADAS Feature	By
Cadillac	Full range hands-free	2016
BMW	Traffic Jam Assist Stop and go up to 25 mph	2014
Ford	Traffic Jam Assist Stop and go highway traffic	2017
Volvo	Traffic Jam Assistance Stop and go up to 31 mph	2014
Mercedes-Benz	Stop-and-Go Pilot Stop and go up to 35 mph	2014

Table 1. Anticipated semi-automated driving systems and date of expected introduction

In a 2012 forecast by Frost & Sullivan, the global ADAS unit shipments in 2020 should exceed the 90 million units, more than 5.5 times the number of ADAS vehicles shipped in the same year (16.2 million). Alongside the growth of the ADAS market and the introduction of new features every year, few companies are currently pursuing market-ready fully autonomous vehicles, which require no interaction from the driver side. Amongst are Google, GM, Mercedes-Benz and Audi; some rumors suggests Apple is as well a stealth developer of Level 4 vehicles.[10]

It is less anticipated that ADAS systems will have the same impact on infrastructure design and urban form as fully autonomous vehicles. Despite the assisted control and improvements to overall safety and performance, ADAS products are not designed to fully replace humans in the driver seat. As long as human interaction is required for the smallest part of the trip, the fleet could not be apprehended as fully autonomous. While some infrastructural changes might trail the incorporation of ADAS and connected vehicles [6] (such as camera networks, sensors and smart lighting infrastructure) their long-term effect on city form should be relatively insignificant. This paper thus refers to fully autonomous vehicles, which their main driving capability is based on a robotic or computational systems. The NHTSA defines a spectrum of automation between man-handled cars, through ADAS vehicles to full autonomy (Table 2).

4.2 Ownership Models

A major question in regards to the impending mass adaptation of AVs is related to the model of car ownership in the age of autonomy. Since AVs are anticipated to self manage demand and could be potentially optimized to operate ceaselessly, future AV fleets could virtually provide shared transportation systems for the entire city, while reducing or fully eliminating the need for private ownership. Contemporary ridesharing[11] platforms such as Uber, Lyft[12] or VIA already offer a synchronized fleet of vehicles that is self-coordinating massive volumes of trips every day. Uber is also one of the first ridesharing companies to openly admit that it is pursuing a driverless fleet to replace its dependency on human drivers.[13]

But the question of ownership is also related to social, cultural and financial notions. Despite the recent decline in private car ownership, in many places across the US owning a car is still apprehended as a symbol of freedom, matureness or financial stability [5]. In a recent BCG and WEF poll done amongst 6000 participants from 10 countries, most participants expressed their wish to maintain ownership over their cars, even if it's capable of self-driving[14]. This approach goes hand-in-hand with the current rates of private car ownership: In the US, ownership rate of private automobiles is nearly 80% (797 out of 1,000 people). In comparison, 800,000 private cars are owned by less than 12% of Singapore's population, as a result of the city's renowned transit system. A recent study form MIT estimated that a fleet of 300,000 autonomous

[10] http://finance.yahoo.com/news/top-5-companies-autonomous-vehicle-143652992.html

[11] Also known as instant ridesharing, dynamic ridesharing, ad-hoc ridesharing or on-demand ridesharing

[12] Lyft had projected 13 million rides per month in 2015, http://techcrunch.com/2015/03/16/a-look-inside-lyfts-books/

[13] http://www.theatlantic.com/technology/archive/2015/12/driverless-secrets/417993/

[14] http://www.usatoday.com/story/tech/2015/11/24/poll-says-buyers-want-self-driving-cars-auto-tech-company-combo/76282004/

shared vehicles could serve the entire population of Singapore (6 million people) within 15-minute waiting time during peak hours.[15]

No-Automation (Level 0)	The driver is in complete and sole control of the primary vehicle controls – brake, steering, throttle, and motive power – at all times.
Function-specific Automation (Level 1)	Automation at this level involves one or more specific control functions. Examples include electronic stability control or pre-charged brakes, where the vehicle automatically assists with braking to enable the driver to regain control of the vehicle or stop faster than possible by acting alone.
Combined Function Automation (Level 2)	This level involves automation of at least two primary control functions designed to work in unison to relieve the driver of control of those functions. An example of combined functions enabling a Level 2 system is adaptive cruise control in combination with lane centering.
Limited Self-Driving Automation (Level 3)	Vehicles at this level of automation enable the driver to cede full control of all safety-critical functions under certain traffic or environmental conditions and in those conditions to rely heavily on the vehicle to monitor for changes in those conditions requiring transition back to driver control. The driver is expected to be available for occasional control, but with sufficiently comfortable transition time. The Google car is an example of limited self-driving automation.
Full Self-Driving Automation (Level 4)	The vehicle is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip. Such a design anticipates that the driver will provide destination or navigation input, but is not expected to be available for control at any time during the trip. This includes both occupied and unoccupied vehicles.

Table 2. U.S. Department of Transportation Policy on Automated Vehicle Development

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