

Future street design and urban planning considering Autonomous Vehicles

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Abstract

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Historically, streets were primarily designed for people's public lives, serving as hubs for cultural exchange and social activities. However, the importance of public lives has been marginalized since the advent of cars, leaving the majority of street spaces for cars. Many serious problems, such as air and noise pollution, climate change, and crime issues, have occurred in the current vehicle-oriented cities. Contemporary urban planners have begun to recognize that prioritizing human well-being and enhancing livability are the key points in the pursuit of sustainable urban development. Nevertheless, the efficacy of such endeavors is constrained by the prevailing dominance of vehicular transportation within today's cities.

The objective of this thesis is to investigate the potential transformation of urban forms through grasping the opportunity of autonomous driving. Thanks to the merits of autonomous driving, future urban planning and design may experience ground shaking changes in a driverless world. This research initially delves into the historical modification of street functions and the ensuing

challenges, such as pollution and safety issues. It also illustrates the significance of autonomous driving in constructing a better city. Then, the thesis discusses the implications of autonomous vehicles to guide urban planners preparing for a driverless world. Next, the thesis presents 3 potential phases of urban planning changes from the present to a driverless world. This section will concentrate on potential city changes in urban planning and propose viable solutions for a sustainable future. Lastly, this thesis presents some urban design ideas for a fully autonomous future and uses Seattle's Belltown neighborhood as a case study to show a possible path which our city could follow from the present to a driverless future.

TABLE OF CONTENTS

List of Figures	iii
List of Tables.....	v
Chapter 1. Introduction	1
1.1 Research Problems & Questions.....	1
1.2 Research Outlines & Research Scope.....	2
Chapter 2. History	4
2.1 The History of Ancient Street Design.....	4
2.2 The Development of Current Road Design.....	5
2.3 The Failure of Current Urban Planning	7
2.4 The Development of Autonomous Vehicle	9
2.5 Debates on Autonomous Vehicle.....	11
2.6 The Opportunity of Urban Planning in the Future.....	15
Chapter 3. Implications	17
3.1 Cost Saving	17
3.2 Travel Mode Choices	18
3.3 Efficiency	19
3.4 Safety	19
3.5 Equity	錯誤! 尚未定義書籤。
3.6 Denser or Rapid Rise in Urban Sprawl.....	21
3.7 Parking Reduction.....	22
3.8 Public Space and Infrastructure	23
3.9 Environment.....	24
Chapter 4. Planning	26
4.1 Urban Scale	26
4.1.1 Urban Pattern.....	29
4.1.2 Land Use.....	32
4.1.3 Transportation System.....	33
4.1.4 Mobility Pattern.....	36
4.2 Phases.....	錯誤! 尚未定義書籤。

4.2.1	Technology Improvement Timeline	39
4.2.2	Development Phases.....	41
4.2.3	Transportation Development	45
4.2.4	SAV Operation Mode.....	47
4.2.5	Policy Pathway	49
Chapter 5. Design		55
5.1	Urban Elements Design	55
5.1.1	Road Types	55
5.1.2	Street Design	58
5.1.3	Parking Lot	65
5.1.4	Shipping.....	70
5.2	Illustrative Example	73
5.2.1	Site: Belltown	73
5.2.2	Selected Example of Urban Surface.....	79
Chapter 6. Conclusion & Future Work		81
Bibliography.....		84

LIST OF FIGURES

Figure 2. 1. Society of Automotive Engineers Automation Levels (Source: Nhtsa.gov, 2018).	9
Figure 4. 1 Automobile Urban Growth vs. AV Urban Growth Pattern.	30
Figure 4. 2 Automobile Urban Pattern vs. AV Urban Pattern.	31
Figure 4. 3 Road Network Hierarchy.	34
Figure 4. 4 Automobile Urban vs. AV Urban Fabric.	35
Figure 4. 5 Public Transit vs. AV Transit Movement.	37
Figure 4. 6 Automobile vs. AV Movement.	38
Figure 4. 7 Automobile vs. AV Trips.	39
Figure 4. 8 Development Timeline of Vehicle Technologies and Mobility Services.	41
Figure 4. 9 Patchwork Concept to Plan and Design a City Considering AVs.	46
Figure 4. 10 Daily Vehicles Required to Meet the Demand of Trips During the Day.	47
Figure 4. 11 CAV Distribution of the City.	49
Figure 5. 1 100' Width Street.	56
Figure 5. 2 100' Width Street with Transit.	56
Figure 5. 3 100' Width Street with Bus.	56
Figure 5. 4 80' Width Street.	57
Figure 5. 5 50' Width Street.	57
Figure 5. 6 50' Width Residential Street.	57
Figure 5. 7 Efficient Surface.	58
Figure 5. 8 Shared Surface.	59
Figure 5. 9 Street Reallocated to Walking Boulevard on Perimeter.	60
Figure 5. 10 Street Reallocated to Walking Boulevard in Center.	61
Figure 5. 11 Mobility Pattern at Intersection.	63
Figure 5. 12 AV Intersection Consisting of Multi-Functional Traffic Beacons.	64
Figure 5. 13 Office Parking in the Present.	65
Figure 5. 14 Office Parking in the Future.	66
Figure 5. 15 Grocery Store Parking in the Present.	67
Figure 5. 16 Grocery Store Parking in the Future.	67

Figure 5. 17 Fast-Food Parking in the Present.	68
Figure 5. 18 Fast-Food Parking in the Future.	69
Figure 5. 19 Grocery Store Delivery in the Present.	70
Figure 5. 20 Grocery Store Delivery in the Future.	71
Figure 5. 21 Home Delivery in the Present.	72
Figure 5. 22 Home Delivery in the Future.	72
Figure 5. 23 The Study Area of Belltown.	74
Figure 5. 24 The Present Road System of Belltown.	75
Figure 5. 25 The Designed Road System of Belltown in 2040.	76
Figure 5. 26 The Designed Road System of Belltown in 2060.	77
Figure 5. 27 Bell Street in the Future.	79

LIST OF TABLES

Table 4. 1 The Historical Impacts of Transportation Technologies (Automobile and Public Transit).	27
Table 4. 2 Comparison Between the Observed Impacts of Automobiles with Possible Impacts of AVs.	29
Table 4. 3 Summary of Effects in Different Phases.	44
Table 4. 4 The Action for the Sustainable Urban Mobility Plan.....	54

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Chapter 1. Introduction

After WWII, the widespread utilization of vehicles and the acceleration of urbanization led to a thorough transformation in street design. The convenience and high efficiency of vehicles gave rise to a new urban type – the automotive city - which brought numerous merits. In consequence, people increasingly relied on vehicles, prompting cities to invest in wider roads and highways to foster national development. This led to the dominance of vehicles on the streets. However, this transition also prompted people to distance themselves from spaces they had cherished for centuries due to urban issues such as noise, pollution, and safety concerns. where they enjoyed for centuries because of many city problems, such as noise, pollution, and safety issues. As a result, the downtown areas, once vibrant, began to feel cold and detached.

In recent years, the development of autonomous vehicles has offered the potential to profoundly reshape our streets, bringing benefits such as enhanced safety, convenience, and intelligence. Therefore, this presents significant opportunities to address present urban problems and to reclaim the streets for human use and capitalize on these benefits.

This chapter will provide an overview of the research plans for this thesis. First of all, it will identify the core research issues and delineate them into specific research questions, thereby illuminating the central objectives of this study. Following this, the thesis will establish the overarching research framework and define the scope of the research, highlighting key focal points in different sections of the thesis.

1.1 Research Problems & Questions

The research problem addressed in this thesis revolves around uncovering the ramifications of autonomous vehicles on urban forms. Its primary aim is to assist urban planners and designers

in comprehending and harnessing the potential opportunities that arise. Because of the uncertainty of the future, the thesis will explore possible implications of autonomous vehicles, encompassing both the advantages and disadvantages. Consequently, this work will summarize a range of approaches for planners and designers to mitigate negative impacts and amplify positive outcomes. The following research questions are raised to break down the research problem into five steps of a research effort:

1. Why are autonomous vehicles important for urban planning and design?
2. What are the implications of automated vehicles on city planning and design?
3. What kind of opportunities will be brought for future urban planning and design?
4. How can urban planning be adapted to create a livable and human-friendly city in a future dominated by autonomous driving?
5. How to change the current street design for a safer and more active street in the autonomous driving future?

1.2 Research Outlines & Research Scope

This thesis predominantly employs qualitative research methods to synthesize relevant literature and presents ideas for future urban planning and street design within the context of widespread autonomous vehicle implementation. The thesis aims to propose feasible urban planning suggestions to create a more livable and human-friendly city in this autonomous driving era. In order to achieve this, gaining a comprehensive understanding of the driverless future is necessary. Consequently, the research is divided into four sections, each focusing on specific research questions and establishing a foundation for subsequent sections.

The first section serves to introduce the history of car-oriented cities prevalent today and discuss the following challenges in the current era. These challenges highlight the shortcomings

of present urban development and emphasize the complexities of finding viable solutions. Subsequently, this thesis delves into the transformative potential of autonomous vehicles, positing that they offer a unique and innovative opportunity for urban planners to reshape cities into more friendly, secure, and sustainable environments.

The second section explores comprehending the future urban condition through a study of the implications of autonomous vehicles on urban planning and design. It collates and examines existing literature to outline the benefits and concerns from an urban planning standpoint. This groundwork equips urban planners and designers to proactively address the imminent challenges of urban development.

The third section elucidates potential modifications in a urban scale as the gradual implementation of autonomous vehicles takes place. Moreover, it delineates three conceivable phases depicting the developmental trajectory from the present to a driverless future.

Bringing the thesis to a close, the final section proposes design interventions at the street level. To exemplify these interventions, Seattle's Belltown serves as a case study, vividly portraying the step-by-step evolution of an urban area from the present to a fully autonomous vehicle-oriented environment.

Chapter 2. History

To comprehend the significance of autonomous vehicles in urban planning, it becomes essential to delve into the challenges currently afflicting cities and the potential benefits that autonomous vehicles are poised to deliver. This chapter seeks to provide a concise overview of the historical evolution of street design while identifying prevailing predicaments within modern urban contexts. Subsequently, the chapter will elucidate the intrinsic advantages that autonomous vehicles bring forth, accompanied by a comprehensive exploration of research endeavors in this domain. This examination aims to underscore the pivotal role that autonomous vehicles hold for urban planners.

2.1 The History of Ancient Street Design

The concept of a street predates the term “street” itself by a significant span of time. As human settlements took shape and buildings were erected in close proximity, the spaces that emerged between these structures bore an initial resemblance to what we now identify as streets. In the context of European civilization, the origins of the street concept can be traced back to ancient cities like Rome or Athens.¹ And the word “street” originated from the Latin *strata* which means a paved road. Throughout ancient times, Streets were usually intertwined with the concept of the “public realm”, which is serving as spaces where people gathered for activities such as trade, leisure, and social interaction.

Given that streets served as vital spaces that people traversed almost every day, they became centers for interaction and commerce. This prompted the establishment of urban focal points like

¹ Dover, Victor, and Massengale, John. *Street Design: The Secret to Great Cities and Towns* (New York: John Wiley & Sons, Incorporated, 2013).

market, church, bourse, and town hall in these areas.² People, whether from rural or urban settings, brought with their home-made products on the streets, exchanging other essential provisions. Thus, the design and layout of streets were significantly influenced by the necessity to accommodate public activities and improve the overall quality of urban life.

The Ancient Romans designed their city with meticulously planned gridiron street patterns and well-constructed roadways to showcase their prowess in engineering and embody their martial spirit. Similarly, within medieval Europe, the function of streets served both defensive and functional purposes, displaying the architectural charm of the era.

2.2 The Development of Current Road Design

During the Renaissance period, urban planning shifted its focus towards emphasizing symmetry, grandeur, and aesthetics. For example, the tree-lined promenades, wide avenues, and ornate buildings of Parisian boulevards showcased the grandeur, regularity, and beauty of the city.

Entering the Industrial Revolution, street design underwent significant transformation. The rapid influx of people into city centers triggered by industrialization led to a remarkable expansion of downtown areas in both density and size. However, this expansion also brought forth a range of challenges, including issues like fires, nuisances, and unsanitary conditions. To address these concerns, urban planners introduced zoning regulations aimed at mitigating certain problems. Yet, several issues persisted. In this era, the streets, in dense city center, were crowded, full of horse manure, and prone to injuries by horse-drawn carts.

The introduction of vehicles marked a turning point, allowing people to cover longer distances without enduring the grimy environment of the past. This newfound convenience and

² Hans Karssenbergh, Jeroen Laven, Meredith Glaser & Mattijs van 't Hoff. *The City at Eye Level - Second and Extended version* (Delft: Eburon, 2016).

comfort rendered cars increasingly popular. Concurrently, increased mobility opportunities fueled the rapid growth of cities, with governments, planners, and residents alike embracing extensive development. This fervor manifested tangibly in the construction of broad roads tailored to accommodate vehicles, thereby catalyzing a profound transformation in the role of automobiles within city planning. Consequently, streets designed primarily for vehicular usage commandeered significant portions of urban space, leading to narrower sidewalks or even their conspicuous absence.

However, this shift also brought a host of significant urban challenges. Notably, cities have become much more segregated now. Without private cars, most individuals could enjoy a comfortable life living in cities with trains, streetcars, and other transportation methods.³ But the pursuit of comfort and livable environment led the affluent to gravitate towards suburban living, leaving downtown areas disorderly and hazardous for those less privileged.

However, because of the high efficiency, the rich prefer living in the suburban area to chase a safer and more pleasant lifestyle, leaving a messy and dangerous downtown space for the poor. This urban sprawl exerted profound influences on both city planning and the lifestyles of the residents. As dependence on private cars grew, routine activities like shopping and commuting now required automobile use. In the United States, car ownership became nearly indispensable, evident in the decline of car-less households from 22% in 1960 to a mere 8.5% in 2020. Concurrently, households with two or more cars surged from 22% in 1960 to a substantial 59% by 2020.⁴

Meanwhile, a range of additional problems came to the fore. Traffic congestion reached unprecedented levels, with research by Rodrigue revealing a threefold increase in the likelihood

³ Dover et al., *Street Design: The Secret to Great Cities and Towns*.

⁴ Jean-Paul Rodrigue, Claude Comtois, Brian Slack. *The Geography of Transport Systems* (New York: Routledge, 2020).

of drivers encountering congestion in the 21st century compared to the latter part of the 20th century.⁵ Moreover, this influx of cars also engendered heightened air pollution and noise levels, significantly compromising overall quality of life. Since 1970, global carbon dioxide emissions have increased by approximately 90%, with a staggering 78% attributed to fossil fuel combustion and industrial processes.⁶ In 2021, the total greenhouse gas emissions of U.S. are about 6,340 million metric tons of CO₂ equivalent, with 29% emissions are from the transportation sector.⁷

Furthermore, the rapid increase of vehicles led to wider roads and increased parking spaces, encroaching upon land which was originally allocated for sidewalks and public spaces. As a result, public activities in markets, agoras, parades or for processions, games, and community interactions, were also affected by increased traffic and associated safety concerns. This further exacerbated the challenges posed by urbanization.⁸

2.3 The challenges of Current Urban Planning

Undoubtedly, the undesirable consequences of the automobile-dominated urban form have led to a decline in people's inclination to walk, engage in recreational activities, or even social interactions on the streets. As a result, our city has shifted its focus away from being human-centric, becoming instead a car-oriented environment. This led to fewer pedestrians and diminished social vibrancy on its streets. This transformation has resulted in the loss of the once vibrant and bustling city we cherished, leaving a city that feels segregated and devoid of warmth.

⁵ Jean-Paul Rodrigue et al., *The Geography of Transport Systems*.

⁶ Boden, T.A., Marland, G., and Andres, R.J., "Global, Regional, and National Fossil-Fuel CO₂Emissions." Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A (2017). doi 10.3334/CDIAC/00001_V2017.

⁷ U.S. Environmental Protection Agency, "U.S. Transportation Sector Greenhouse Gas Emissions 1990-2021" (Washington, D.C.: U.S. Environmental Protection Agency, 2023), <https://www.epa.gov/system/files/documents/2023-06/420f23016.pdf>.

⁸ Jean-Paul Rodrigue et al., *The Geography of Transport Systems*.

Scholars have highlighted that the assumed highest priority of city street design is automotive speed and only the denizens of those well-padded interiors get the benefit.⁹ On the other hand, the significance of public spaces cannot be overstated.¹⁰ Throughout human history, cities have consistently served as pivotal gathering places, and most human culture has occurred in public spaces. Among these spaces, streets hold a unique and central position as the most common place to be frequently utilized. Consequently, many urban planners are actively endeavoring to design streets that prioritize human well-being and encourage non-motorized transportation.

Furthermore, the street, as the most common and frequently used place for people experiencing every day, is one of the most important public spaces. Therefore, many urban planners are trying to construct a human-friendly and non-motorized transportation encouraged street. However, the effect is limited. With so many car ownerships, driving demands are globally essential especially in the United States. Any large-scale reduction of driving roads will lead to severe traffic congestion in our city. Meantime, with the culture that everyone needs a car, car ownership and driving demands are still increasing. Therefore, it is really difficult for the planners to reduce some driving land use and increase sidewalk and public spaces.

Nonetheless, efforts of such changes encounter inherent limitations. The widespread ownership of automobiles and the demand for vehicles remains deeply entrenched, especially in places like the United States. Large-scale reductions in driving lanes would precipitate server traffic congestion. In addition, the deeply ingrained belief that everybody needs a car further increased the difficulty. With the persistent growth in car ownership, urban planners face a

⁹ Ladd, Brian. "Are We There Yet? The American Automobile Past, Present, and Driverless by Dan Albert (review)." *The Michigan Historical Review* 46, no. 1 (2020): 167–68. doi:10.1353/mhr.2020.0024.

¹⁰ Gehl, Jan. *Life Between Buildings: Using Public Space*. Washington: Island Press, 2011.

significant challenge in attempting to relocate some urban spaces from driving lanes to sidewalks and public areas.

2.4 The Development of Autonomous Vehicle

Advancements in electric vehicle technology and the imminent prospect of autonomous driving bring a ray of hope, presenting new opportunities for urban planners. To comprehend the potential impact of autonomous driving on urban planning, a fundamental understanding of this technology is imperative. The Society of Automotive Engineers (SAE) has established a classification system consisting of six levels of driving automation, ranging from Level 0 to Level 5, which is also adopted by the US Department of Transportation (DOT).¹¹ This classification, delineated in SAE J 3016-2021, serves as Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles.

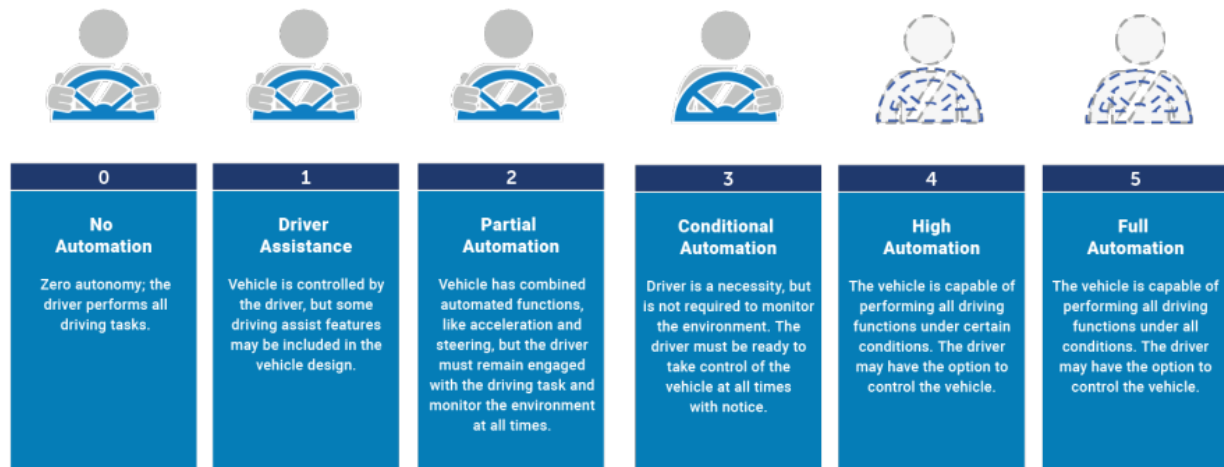


Figure 2. 1. Society of Automotive Engineers Automation Levels.¹²

Figure 2.1 visually illustrates the distinctions between these levels. The progression from Level 0 to Level 2 involves drivers gradually employing supportive driving features while

¹¹ Halberg, Alicia A. "Preparing for an Autonomous Future Transportation Planning for Autonomous Vehicles in the Puget Sound Region." PhD diss., ProQuest Dissertations Publishing, 2018.

¹² "The Road to Full Automation," NHTSA, <https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety>.

maintaining continuous supervision. Essentially, the responsibility of driving remains with the individual. Level 0 encompasses basic automatic emergency braking and blind spot warning features. Level 1 permits driver assistance, but all actions are performed by the driver. At Level 2, drivers can leverage features such as acceleration and brake assistance, but must remain fully engaged in supervising the vehicle.

As advancing to Level 3, a new dimension emerges, introducing conditional autonomous functions like pilot parking and autopilot mode within controlled and predictable environments. However, human intervention continues to be needed when the feature request. The true autonomy of Level 4 and Level 5 marks a significant shift. Only when the driving automation level goes to level 4 or 5, autonomous cars will not require drivers to take over driving.¹³ At Level 4, fully autonomous vehicles can manage most driving tasks independently, with human override still available in situations requiring assistance. Level 5 signifies the zenith, where autonomous driving is able to complete all tasks without human assistance in any given situation.¹⁴

In the present, there are two distinct paths propelling the future of Autonomous Vehicles (AVs): the evolutionary and revolutionary approaches. The "evolutionary path" involves gradual increases in a vehicle's level of automation, primarily championed by traditional automobile manufacturers. On the other hand, the "revolutionary path," embraced by companies like Tesla and Waymo, strives for complete autonomous driving from the outset, gradually implementing this capability across diverse conditions.¹⁵ Waymo, for instance, exemplifies the revolutionary

¹³ SAE International. Surface Vehicle Recommended Practice. Taxonomy and Definitions for Terms Related to Driving Automation Systems for ON-Road Motor Vehicles, J3016. (Revised 2018)

¹⁴ Serio Agriesti, Fausto Brevi, Paolo Gandini, Giovanna Marchionni, Rahul Parmar, Marco Ponti, and Luca Studer, "Impact of Driverless Vehicles on Urban Environment and Future Mobility," *Transportation Research Procedia*, Volume 49 (2020): 44-59. <https://doi.org/10.1016/j.trpro.2020.09.005>.

¹⁵ Pierluigi Coppola, Domokos Esztergár-Kiss, "Autonomous Vehicles and Future Mobility," Elsevier, (2019): 1 – 15.

approach through its testing and deployment strategy. The company begins by conducting tests on some residential streets in Austin. Members of the public in areas like Phoenix and San Francisco are given access to autonomous vehicles as the technology matures. Waymo plans to test its fifth-generation driver across diverse areas such as central and East Austin, showcasing their commitment to pushing the boundaries of autonomous technology.¹⁶

2.5 Debates on Autonomous Vehicle

The rise of autonomous vehicles (AVs) has become a prominent subject of contemporary research, triggering extensive debates regarding their potential to shape a positive or detrimental future. With the growing adoption of AVs, there is a consensus among researchers that they will significantly transform urban form and mobility, because of countless unique features. While discussions persist about the timeline, method, and extent of AV integration into the market, one certainty prevails that future vehicles will eventually be fully automated.¹⁷

In comparison to human drivers, AVs may exemplify a risk-averse demeanor, dutifully adhering to traffic regulations and prioritizing safety. Pedestrians will gain a strategic advantage while walking on streets, as they can confidently anticipate AVs yielding to them.¹⁸ Additionally, the introduction of AVs will hold the promise of addressing social equity concerns, reducing the need for parking spaces, and narrowing driving lanes within urban environments.¹⁹ Optimized driving behavior and AI-controlled systems will enable AVs to require less distance and fewer

¹⁶ The Waymo Team, "Expanding Waymo's testing to the city that keeps it weird", WAYMO, March 31, 2023. <https://waymo.com/blog/2023/03/expanding-waymos-testing-to-austin.html>

¹⁷ Gawne, Joshua, Kenneth Yocom, Manish Chalana, and Kenneth (Kenneth Peter) Yocom. "Rethinking the Right-of-Way: Exploring Seattle's Autonomous Future." [University of Washington Libraries], 2018.

¹⁸ Millard-Ball, Adam. "Pedestrians, Autonomous Vehicles, and Cities." *Journal of Planning Education and Research* 38, no. 1 (2018): 6–12. doi:10.1177/0739456X16675674.

¹⁹ Halberg, Alicia A, "Preparing for an Autonomous Future Transportation Planning for Autonomous Vehicles in the Puget Sound Region".

lanes to accommodate higher vehicular density, ultimately leading to a significant reduction in congestion.

Furthermore, AVs will provide new mobility choices for individuals who are unable to drive independently, such as disabled individuals and seniors. Nikolaos Gavanas presents a comprehensive exploration of AVs' potential impacts and challenges within urban planning.²⁰ This includes not only an acknowledgment of equity issues but also the introduction of opportunities related to land use and shared transportation methods. According to Nikolaos Gavanas' research, 95% time of private cars are parked in Europe²¹ and nearly 30% of the traffic in city center is for searching parking spaces.²² The full implementation of AVs could enable collaboration between specialized sectors and private corporations to collect extensive data, encompassing travel patterns, road conditions, air quality, noise levels, and more, to evaluate and improve transportation systems.

Moreover, the introduction of AVs may yield two opposing implications for urban development: the densification of city centers and the expansion of urban sprawl.²³ Shared autonomous vehicles (SAVs) could drive re-densification by facilitating mixed land development around transportation hubs, given their potential to increase accessibility to city centers. However, AVs could also attract more residents to peripheral areas, leading to the segregation of residential area from workplaces.

²⁰ Gavanas, Nikolaos. "Autonomous Road Vehicles: Challenges for Urban Planning in European Cities." *Urban Science* 3, no. 2 (2019): 61–. doi:10.3390/urbansci3020061.

²¹ "Driverless Cars Increase Congestion—But Could Cut Massive Parking Times," *Transportation & Environment*, January 9, 2017. <https://www.transportenvironment.org/news/driverless-cars-increase-congestion-%E2%80%93-could-cut-massive-parking-times>.

²² Lessons from Zurich, Vienna and Munich, "Traffic Calming in Three European Cities", SPIR. September 1, 2004 <https://www.spur.org/publications/urbanist-article/2004-09-01/traffic-calming-three-european-cities>.

²³ Jeong, Jindo, Juhyun Lee, and Tae-Hyoung Tommy Gim. "Predicting Changes in the Built Environment in the Era of Vehicular Automation: A Review." *Journal of Planning Literature* 38, no. 2 (2023): 215–28. doi:10.1177/08854122221138530.

Furthermore, RethinkX²⁴, as one of the most comprehensive, speculative, alarming, and attention-grabbing automated vehicle publication²⁵, potentially transformative business model called transport-as-a-service (TaaS). According to their projections, TaaS could become 4 to 10 times cheaper than the current private car model within 10 years of regulatory approval. RethinkX also predicts that 95% of passenger miles traveled in the United States will adhere to the TaaS model, resulting in a substantial reduction of passenger cars on American roads, from 247 million to 44 million, over the next 10 years.

However, some researchers are skeptical of RethinkX's projections, noting that the publication may be overly optimistic in terms of the speed of full commercialization and widespread adoption of automated vehicles. These critics highlight various barriers, including regulatory, social, and installed-base challenges, that could hinder the realization of RethinkX's vision. From a customer's perspective, the immediate benefits, effectiveness, and reliability of non-automated and partially automated vehicles are likely to remain superior to fully automated vehicles for the foreseeable future. The timeline for RethinkX's vision might extend beyond 2050.^{26 27}

Despite the potential benefits discussed earlier, the widespread implementation of automated vehicles could also have adverse effects.²⁸ As automated vehicles become prevalent, many individuals engaged in traditional transportation services may face job displacement. Additionally, due to the enhanced comfort and efficiency of automated vehicles, wealthier individuals might live

²⁴ James Arbib & Tony Seba, "Rethinking Transportation 2020-2030: The Disruption of Transportation and the Collapse of the Internal-Combustion Vehicle and Oil Industries," RethinkX, May 2017.

²⁵ Grush, Bern, and John Niles. *The End of Driving: Transportation Systems and Public Policy Planning for Autonomous Vehicles*. (Amsterdam, Netherlands :: Elsevier, 2018).

²⁶ Nieuwenhuijsen, J., "Diffusion of automated vehicles: a quantitative method to model the diffusion of automated vehicles with system dynamics." Delft University of Technology, 2015.

²⁷ S. Shladover. "What 'Self-Driving' Cars Will Really Look Like," Scientific American, June 1, 2016) June. <https://www.scientificamerican.com.offcampus.lib.washington.edu/article/what-self-driving-cars-will-really-look-like/>

²⁸ Grush, Bern te al., *The End of Driving: Transportation Systems and Public Policy Planning for Autonomous Vehicles*.

further and opt for extended travel in their private cars, leading to further urban sprawl. Middle- and low-income individuals may increasingly rely on shared automated vehicles instead of walking or using public transit, potentially reducing street-level activity and exacerbating suburban sprawl. This trend could exacerbate social segregation within cities.

Then, even though automated vehicles will release a large amount of transportation land, streets will not revive if there is no investment in this area. Furthermore, the introduction of Shared Automated Electric Vehicles (SAEVs) may bring uncertain consequences for urban mobility.²⁹ While SAEVs could enhance efficiency and convenience, they might also increase overall travel demands, potentially straining urban mobility systems.^{30 31} To mitigate this, public transit and policies should be planned alongside the development of SAEVs, with a focus on reducing car ownership and promoting non-motorized transportation (NMT).³²

Due to the large-scale implementation of cars, the car dependence led to increased social segregation, abysmally high traffic fatalities, longer commutes time, and significant climate changes. Surprisingly, the US has the worst per capita fatality rate in the industrialized world. Therefore, cities must grasp this opportunity to reshape the city for safety goals, better transit service, and reducing carbon emissions.³³ Governments and urban planners need to carefully navigate this transformative era, leveraging the potential advantages of automated vehicles to create livable and human-oriented urban environments. Strategic investments, such as repurposing the transportation land into public spaces, can contribute to this vision. The two potential markets

²⁹ Adam Stocker, Susan Shaheen, PhD, "Shared Automated Mobility: Early Exploration and Potential Impacts. Transportation Sustainability Research Center," University of California, Berkeley, June 1, 2017. <https://escholarship-org.offcampus.lib.washington.edu/uc/item/5d55s8sp>.

³⁰ Hymel, Kent M., Kenneth A. Small, and Kurt Van Dender. "Induced Demand and Rebound Effects in Road Transport." *Transportation Research. Part B: Methodological* 44, no. 10 (2010): 1220–41. doi:10.1016/j.trb.2010.02.007.

³¹ Aggelos Soteropoulos, Martin Berger & Francesco Ciari, "Impacts of automated vehicles on travel behaviour and land use: an international review of modelling studies." *Transport Reviews*, 39 (2019), 29-49. DOI: 10.1080/01441647.2018.1523253

³² "Shared mobility principals for livable cities," Shared mobility principals for livable cities, <https://www.sharedmobilityprinciples.org/>.

³³ Corinne Kisner, Kate Fillin-Yeh, NACTO, Sindhu Bharadwaj. "Blueprint for Autonomous Urbanism" National Association of City Transportation Officials, September 2019. <https://nacto.org/publication/bau2/>

for automated vehicles – shared and individual – present distinct trajectories for urban development. If shared autonomous electric vehicles (SAEVs) undergo complete development, car ownership would be highly reduced, and a great number of transportation lands could be transformed into public spaces. But if individual automated vehicles are developed, car ownership would still increase, and city segregation could worsen due to the higher efficiency and interior comforts compared to current transit. Therefore, how to conduct the new revolution of automated vehicles is significant for our government and urban planners.

2.6 The Opportunity of Urban Planning in the Future

In the section on streets design development, this thesis explored how historical urban planning and the widespread integration of automobiles have addressed various urban challenges since the onset of the Industrial Revolution. Nevertheless, numerous new challenges have emerged. Presently, our city grapples with a multitude of social and planning issues, including downtown crime, vehicle-oriented design, segregation, suburban sprawl, and more. Despite the concerted efforts of urban planners and designers to tackle these challenges, their impact remains limited due to the prevailing dominance of cars within the urban landscape.

In September of the previous year, Tesla made a significant announcement regarding the expansion of its Full Self-Driving (FSD) software. From its initial adoption by a few thousand owners, the technology was extended to a remarkable 160,000 owners in North America.³⁴ In contrast to autopilot which is just a support driving system – people must hold their steering wheels and mostly could only be used on highways, FSD could be used anywhere without holding steering

³⁴ Simon Alvarez, "Tesla FSD Beta 10.69.2.2 extending to 160k owners in US and Canada: Elon Musk", TESLARATI, September 20, 2020. <https://www.teslarati.com/tesla-fsd-beta-10-69-2-2-160k-owners-us-canada-elon-musk/>.

wheels. Since the responsibility still lies with the driver, the driver must get ready to control Tesla at all times. But this is also a great step for autonomous driving technology.³⁵

While debates and challenges surrounding autonomous vehicles endure, there is an undeniable truth: automated vehicles constitute an integral part of the future. The current juncture in urban planning marks a crucial point for development, as automated driving has the potential to usher in new opportunities for a more promising world. It remains a difficult task to determine whether technology will solve the problems or make them worse, but, in fact, autonomous driving technology cuts both ways – autonomous vehicles will bring tremendous benefits and risks. The key lies in carefully weighing these benefits and challenges, diligently exploring every conceivable consequence.³⁶ It is a vital task for urban planners to leverage the benefits and mitigate the risk by integrating autonomous vehicles into city development and creating plans.

As we envision a driverless future, those benefits, which are mentioned before, should not mean an unequivocal embrace of new technology. Meanwhile, concerns and worries about new technology also should not prevent the development or implementation of autonomous vehicles. Instead, urban planning should shift to build equitable, livable, and sustainable cities which will thrive as the new technology comes into everyone's life.³⁷

³⁵ Fred Lambert, "Tesla expands its Full Self-Driving Beta to 60,000 more owners", *electrek*, September 19, 2022. <https://electrek.co/2022/09/19/tesla-full-self-driving-beta-expands-owners/>

³⁶ Grush, Bern, and John Niles. *The End of Driving: Transportation Systems and Public Policy Planning for Autonomous Vehicles*.

³⁷ Fox, Sarah. "Planning for Density in a Driverless World." *SSRN Electronic Journal*, n.d. 2016. doi:10.2139/ssrn.2735148.

Chapter 3. Implications

Even though there are many debates and concerns about autonomous vehicles, one thing cannot be denied: the vision of a driverless world is inevitable. Therefore, it is important for urban planners to understand how autonomous vehicles will impact everyone's lives. Therefore, to gain a comprehensive understanding of the implications is necessary for urban planners. As this thesis discussed earlier, the impact of AVs is potentially groundbreaking. It will not only change the behavior of drivers but also reshape cities in many aspects.

3.1 Cost Saving

Undeniably, cost is one of the most important factors in people's mode choices. Globally, labor cost is about 40% - 60% of total management cost for all public transit. The forthcoming implementation of autonomous vehicles will remarkably reduce this cost. This projection is further bolstered by the inherent efficiency of autonomous buses, which have the potential to accommodate a larger number of passengers compared to their human-driven counterparts. According to a study by Princeton University, autonomous buses on the bus lanes of the Lincoln Tunnel can carry more than 200,000 customers per hour, which is over 5 times more than usual buses. This shows autonomous vehicles could both increase the efficiency and decrease the cost of public transit.³⁸

According to the U.S. FHWA's Highway Economic Requirements, the operating costs (which include driving, cleaning and management costs) of vehicles typically average from

³⁸ Agriesti Serio, Fausto Brevi, Paolo Gandini, Giovanna Marchionni, Rahul Parmar, Marco Ponti, and Luca Studer. "Impact of Driverless Vehicles on Urban Environment and Future Mobility." *Transportation Research Procedia* 49 (2020): 44–59. doi:10.1016/j.trpro.2020.09.005.

approximately \$0.30 to \$0.42 per car-mile.³⁹ Meanwhile, A report from Victoria Transport Policy Institute points out that the total cost for buses and light rail is about \$0.94 and \$0.42 per mile, respectively, but individual payment is only \$0.24 and \$0.19 per mile.⁴⁰ In terms of autonomous vehicles, some researchers estimate the price of purpose-built shared AVs (SAVs), used as pooled taxis, to be only \$0.16 per mile.⁴¹ others provide a more approximate but more transparent estimate, suggesting that the cost of fully SAVs is less than \$0.20 per mile, but no more than \$0.30 per mile.⁴² Meanwhile, some optimistic researchers illustrate the future cost of AVs could be as low as \$0.15 per mile.⁴³

3.2 Travel Mode Choices

However, mode choices are not solely determined by cost. Based on Bliss's study in Chicago, the research compared the cost for Uber and Lyft vs. Public transit. Even though the cost of ride-hailing is 4 times higher than that of public transit, many people still opt for ride-hailing due to factors such as comfort and time savings. In conclusion, while cost is undeniably one of the most important factors influencing mode choices, other factors can also significantly impact people's decisions.⁴⁴ Therefore, even if the cost of AVs or SAVs is not lower than that of public transit, advantages such as comfort and high efficiency will undoubtedly attract a substantial number of customers. Further detailed research is presented below.

³⁹ "Exhibit A-9: Highway Investment Analysis Methodology," Highway Economic Requirements System, Federal Highway Administration, October 8, 2021. <https://www.fhwa.dot.gov/policy/24cpr/>.

⁴⁰ "Transportation Cost and Benefit Analysis II – Vehicle Costs," Institute of Victoria Transport Policy, December 1, 2022. <https://www.vtpi.org/tca/tca0501.pdf>.

⁴¹ Agriesti Serio et al., "Impact of Driverless Vehicles on Urban Environment and Future Mobility."

⁴² T.S. Stephens, J. Gonder, Y. Chen, Z. Lin, C. Liu, D. Gohlke. "Estimated Bounds and Important Factors for Fuel Use and Consumer Costs of Connected and Automated Vehicles." United states: National Renewable Energy Lab. (NREL), Golden, CO (2016).

⁴³ Burns, L. D., Jordan, W. C., & Scarborough, B. A." Transforming Personal Mobility." New York: The Earth Institute, Columbia University, 2013.

⁴⁴ Bliss, L. "The High Cost of Saving Travel Time". City Lab, June 28, 2018. <https://www-citylab-com>.

3.3 Efficiency

Autonomous vehicles are controlled by computers, which require less reaction time than humans and can maintain smooth traffic flow on the road. As a result, higher safety speed limits and reduced congestion would be some of the benefits of a driverless world. Furthermore, since a significant portion of downtown traffic is caused by vehicles searching for parking⁴⁵, individuals can leave their AVs to drive on the road or search for parking by themselves.⁴⁶ Clearly, AVs will significantly enhance people's mobility.

3.4 Safety

In fact, non-motorized transportation (NMT) groups are the ones that face the highest risk in crashes. Since pedestrians and cyclists lack the protective "shell" that cars have to reduce the impact of collisions.⁴⁷ AVs have larger fields of vision and quicker reaction times compared to people on the road, enabling them to prevent crashes caused by drivers' distracted driving. A study shows that currently, human drivers only pay attention to driving 25% of the time, with 75% of the time being spent inattentively while driving.⁴⁸ Because on-board software can control vehicles more efficiently, it is believed that AVs will significantly reduce the number of accidents. However, some research suggests that this might be true only when complete automation is implemented in all vehicles, and it may not hold when AVs share the road with human drivers. In fact, issues regarding pedestrian and cyclist safety become even more critical when sharing lanes.⁴⁹ Therefore,

⁴⁵ Shoup, Donald, ed. *Parking and the City*. New York: Routledge, 2018.

⁴⁶ Shoup, Donald C. *The High Cost of Free Parking*. Updated. Chicago: Planners Press, American Planning Association, 2011.

⁴⁷ Vissers, L., Kint, M. S., MSc, I. v., & Hagenzieker, P. M. *Safe interaction between cyclists, pedestrians and automated vehicles*. (Hague: SWOV Institute for Road Safety Research, The Netherlands, 2016)

⁴⁸ Noah Zon & Sara Ditta, "Robot, take the wheel Public policy for automated vehicles." Toronto: Mowat centre, Ontario Voice on Public Policy, 2016.

⁴⁹ Agriesti Serio et al., "Impact of Driverless Vehicles on Urban Environment and Future Mobility."

during the implementation of AVs, essential AV facilities like sensors, cameras, and signals should be meticulously integrated to ensure the safety of all road users.

3.5 Equity

AVs will not only impact the mobility patterns of human society but also have the potential to create a more equitable world. In fact, AVs can offer opportunities for individuals who are unable to drive, such as the elderly and disabled. These groups have historically relied on others for their mobility needs, but AVs could provide them with independent and practical solutions, granting them greater freedom of movement in the future.⁵⁰

Self-driving technology has begun to be tested in some rural communities, such as Nishikata, a small town located 71 miles north of Tokyo. In such communities, where elderly residents have limited access to fewer bus and taxi services due to the aging and shrinking population, self-driving vehicles could alleviate transportation challenges faced by elderly residents.⁵¹ Julian Brinkley, a researcher at the University of Florida, has developed a program named 'atlas' to assist blind people in using self-driving cars. This program uses the data he collects to better understand the needs of blind individuals when utilizing self-driving cars.⁵² Additionally, Waymo is beginning to test its AVs on the road and design specific features to cater to the needs of disabled people.⁵³ A startup named Optimus Ride, based in Cambridge, Massachusetts, is also testing autonomous transportation for students and staff members within a controlled zone at the Perkins School for the Blind.⁵⁴ A provocative design is using autonomous school bus for safely moving child through

⁵⁰ Agriesti Serio et al., "Impact of Driverless Vehicles on Urban Environment and Future Mobility."

⁵¹ Naomi Tajitsu, "Japan trials driverless cars in bid to keep rural elderly on the move", REUTERS, September 12, 2017. <https://www.reuters.com/article/us-japan-elderly-selfdriving/japan-trials-driverless-cars-in-bid-to-keep-rural-elderly-on-the-moveidUSKCN1BN0UQ>

⁵² Jason Dearen, "Transforming the Autonomous Vehicle Experience for the Blind", UF, April 13, 2018. <https://www.eng.ufl.edu/newengineer/news/transforming-the-autonomous-vehicle-experience-for-the-blind/>.

⁵³ Carlos Granda, "Waymo driverless cars being tested in SoCal for ride-hailing service. Are they safe?", EYEWITNESS NEWS, December 9, 2022. <https://abc7.com/waymo-cars-ride-hail-driverless-vehicles-autonomous/12541908/>.

⁵⁴ Elizabeth Woyke, "The Blind Community Has High Hopes for Self-Driving Cars", MIT Technology Review, October 12, 2016. <https://www.technologyreview.com/2016/10/12/157034/the-blind-community-has-high-hopes-for-self-driving-cars/>.

traffic.⁵⁵ All of these examples highlight the significant benefits of autonomous vehicles for these underserved groups.

3.6 Denser or Rapid Rise in Urban Sprawl

According to the literature research on AVs mentioned before, the advent of autonomous vehicles will give rise to two possible scenarios for the future. One envisions our cities continuing to sprawl, while the other will create a more efficient, denser, and pedestrian-friendly urban environment.⁵⁶

The first scenario paints a bleak picture of our non-stop growing cities. Among the merits of AVs discussed earlier, one notable aspect is that people will be able to reach a broader range of areas within the same amount of time due to the heightened efficiency of AVs.

People can reach a larger range of areas spending the same amount of time because of the high efficiency of AV. Historically, new transportation technologies have led to expansion of urban areas, and this increase in urban space essentially corresponds to the area that people could utilize with the time saved on mobility. Autonomous vehicles will reduce the cost—both in terms of time and effort—associated with driving. People may even work during the commute. Therefore, suburban areas are expected to experience significant growth in a driverless future. This expansion will, in turn, result in increased car ownership as mobility becomes more accessible. Unfortunately, this rise in car ownership will lead to a decline in population density, triggering a corresponding increase in road density. The greater number of vehicles will necessitate additional parking spaces, thereby continuing the current urban sprawl and failing to address existing urban issues.⁵⁷

⁵⁵ Aarian Marshall, "Who's Ready to Put Their Kid on a Self-Driving School Bus? A provocative design concept asks questions about burgeoning tech." WIRED, November 1, 2017. <https://www.wired.com/story/self-driving-school-bus/>.

⁵⁶ Agriesti Serio et al., "Impact of Driverless Vehicles on Urban Environment and Future Mobility."

⁵⁷ Fox, Sarah. "Planning for Density in a Driverless World."

The alternative scenario paints an optimistic picture of a driverless world. In this vision, our transportation system will integrate public transit systems to address extensive or long-distance travel, while shared autonomous vehicles (SAVs) will provide the crucial last mile connectivity. All these transportation resources will be interconnected through the Internet, with Artificial Intelligence (AI) managing seamless transfers for individuals and optimizing SAV usage both economically and socially. In this context, predominant types of autonomous vehicles will function as a service, granting individuals various choices based on factors such as cost, comfort, and efficiency. As a result, car ownership is expected to substantially decline due to the convenience, affordability, and comfort of SAVs. With reduced parking demands, vast tracts of land dedicated to transportation can be reclaimed for the purpose of building a healthier, more sustainable, and fitting urban environment. A growing number of individuals will choose to reside in urban areas and choose healthier mobility alternatives in the years to come, leading to denser yet healthier downtown regions.

3.7 Parking Reduction

In the present, parking remains a significant urban challenge. Typically, people will not perceive how much time and space will be taken up for parking. Individuals could spend approximately 17 hours per year searching for parking.⁵⁸ Additionally, research estimates indicate that parking spaces can occupy as much as 25% to 30% of the entire city.⁵⁹ What's worse, some papers reveal that, on average, 90% of a car's lifespan is devoted to parking.⁶⁰ These statistics underscore the inefficiency of our cities in parking.

⁵⁸ Gora, Paweł, and Inga Rüb. "Traffic Models for Self-Driving Connected Cars." *Transportation Research Procedia* 14 (2016): 2207–16. doi:10.1016/j.trpro.2016.05.236.

⁵⁹ Charlie Gardner, "We Are the 25%: Looking at Street Area Percentages and Surface Parking", *OLD urbanist*, December 12, 2011. <https://oldurbanist.blogspot.com/2011/12/we-are-25-looking-at-street-area.html>.

⁶⁰ Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*. Milton: Routledge, 2018. doi:10.4324/9781351134033.

The primary contributors to this issue are the combined factors of land-use development and minimum parking requirements. Fortunately, the implementation of autonomous vehicles may address this challenge. In a driverless world, individuals can simply leave their cars at their destinations, allowing the vehicles to autonomously locate parking spaces. Furthermore, drivers might pre-schedule their cars to arrive in advance, picking them up automatically when needed. Moreover, parking infrastructure, such as parking buildings, could become more sophisticated and autonomous, thereby minimizing parking space wastage.

Consequently, the need for parking spaces in the future could be diminished. A study conducted in the city of Atlanta illustrates this point. The research found that out of an estimated 500,000 parking spaces, around 25,000 spaces could be eliminated. This study shows that once AVs begin to serve 5% of the travel, parking land use could be reduced by about 4.5% in the City of Atlanta.⁶¹

3.8 Public Space and Infrastructure

In research focused on land use considerations with respect to AVs, multiple researchers propose potential modifications to road spaces, public areas, and related facilities for the implementation of AVs.⁶² Street areas, the number of traffic lanes, and lane widths are likely to decrease due to the advantages of AVs.⁶³ The reclaimed space can be re "For example, Pape and Ferreira propose that the parking spaces saved could be transformed into cycling lanes or pedestrian infrastructure, thereby enhancing the livability and walkability of the city.⁶⁴ These

⁶¹ Zhang, Wenwen, and Subhrajit Guhathakurta. "Parking Spaces in the Age of Shared Autonomous Vehicles: How Much Parking Will We Need and Where?" *Transportation Research Record* 2651, no. 1 (2017): 80–91. doi:10.3141/2651-09.

⁶² Lee, Sunghee, Kee Moon Jang, Nayoon Kang, Jaeman Kim, Minseok Oh, and Youngchul Kim. "Redesigning Urban Elements and Structures Considering Autonomous Vehicles: Preparing Design Strategies for Wide Implementation in Cities." *Cities* 123 (2022): 103595–. doi:10.1016/j.cities.2022.103595.

⁶³ Dirk Heinrichs. "Autonomous Driving and Urban Land Use." In *Autonomes Fahren*. Germany: Springer Berlin / Heidelberg, 2016, 213 - 231 doi:10.1007/978-3-662-48847-8_11.

⁶⁴ Papa, Enrica, and António Ferreira. "Sustainable Accessibility and the Implementation of Automated Vehicles: Identifying Critical Decisions." *Urban Science* 2, no. 1 (2018): 5–. doi:10.3390/urbansci2010005.

proposed transformations not only augur functional improvements but also hold the promise of elevating the visual allure and overall appeal of the urban milieu.⁶⁵

Simultaneously, transportation facilities will undergo substantial transformation. Parking structures can become autonomous and sophisticated, as cars can park themselves and exit these facilities automatically. The location of gas stations, garages, charging stations and other car servicing and utility structures will shift to less prominent locations.⁶⁶ The integration of digital control systems, such as sensors, cameras, and internet-enabled facilities, will be imperative to maintain the safety of AVs.⁶⁷

3.9 Environment

Autonomous Vehicles (AVs) also make a positive contribution to environmental concerns. These vehicles possess the capacity to optimize a multitude of factors, encompassing routes, speeds, and driving patterns, while also engaging in seamless communication with other AVs and infrastructure elements. This serves to refine traffic flow dynamics, thereby enhancing energy efficiency and mitigating wastage and atmospheric pollutants.

Furthermore, an environmentally advantageous aspect of AVs emerges from their prevalent utilization of electricity, reducing dependence on fossil fuels and curtailing emissions. A substantial subset of AVs operates as electric vehicles (EVs), bolstering the transition towards cleaner energy sources.

Another key environmental benefit is engendered through the facilitation of shared mobility services, including ride-sharing and carpooling. This mode of operation will reduce the overall

⁶⁵ Stead, Dominic, and Bhavana Vaddadi. "Automated Vehicles and How They May Affect Urban Form: A Review of Recent Scenario Studies." *Cities* 92 (2019): 125–33. doi:10.1016/j.cities.2019.03.020.

⁶⁶ Ariel Noyman et al., "Roadmap for Autonomous Cities: Sustainable Transformation of Urban Spaces."

⁶⁷ Papa, Enrica, and António Ferreira. "Sustainable Accessibility and the Implementation of Automated Vehicles: Identifying Critical Decisions."

Vehicle Miles Traveled (VMT), which in turn yields a corresponding reduction in greenhouse gas emissions.

Moreover, considering urban density, high density cities will have less impact on environment than low density cities.⁶⁸ AVs, in conjunction with their ability to promote shared mobility and optimize transportation networks, have the potential to further fortify the ecological merits of densely populated cities.

⁶⁸ Baojun, Y. "Planning strategies for liveable high density cities." *Urban Solutions* (1), 2012, 76-79.

Chapter 4. Planning

The introduction of AVs will bring about a radical change to our cities. As delineated in Chapter 3, it will not only affect people's driving behavior, but also affect the urban form, land use, and transportation infrastructures, etc. In this chapter, the thesis will first envision an optimistic picture of a future with highly implemented AVs, introducing possible changes at urban scale and illustrating them separately. Such serves to portray a prospective manifestation of an autonomous urban milieu. Subsequently, this chapter will introduce potential development phases that delineate the incremental transition of the contemporary urban milieu towards a driverless future.

4.1 Urban Scale

The pervasive adoption of novel technologies invariably ushers in a multitude of transformations within the urban form. To prognosticate the forthcoming implications of autonomous vehicles at an urban scale, one of the optimal approaches involves a review of the ramifications stemming from the deployment of automobiles and light rail systems. Such an analysis offers a concise comprehension of the interrelationships existing between the novel technological implementations and urban scale impacts. Subsequently, leveraging the insights gleaned from this antecedent investigation, the present thesis will extrapolate to anticipate the potential trajectories of future urban-scale alterations.

Area of Impact	Examples
Urban Pattern	Urban Growth, Urban Sprawl, Downtown Densification
Land use	Land use modification, Segregation, Street Parking, Parking Building
Transportation System	Transportation System, Infrastructure
Mobility Patterns	Traffic congestion, Shared Cars, etc.

Table 4. 1 The Historical Impacts of Transportation Technologies (Automobile and Public Transit).

Table 4.1 delineates the historical impacts engendered by transportation technologies, including automobiles and public transit. The incorporation of automobiles has catalyzed an unprecedented proliferation of modern urban centers, allowing individuals to reside in more distant locales in pursuit of enhanced lifestyles and environmental conditions, due to increased efficiency. In this research, the thesis simplifies the connection between urban growth and the efficiency of new transportation technologies. This research assumes that people are willing to allocate the same amount of time for commuting. Consequently, it becomes evident that the travel time across the expanded urban area will simply equal the time saved by traveling to the original area by automobiles. Meanwhile, parking is gaining increasing importance due to the rapid growth of car ownership, particularly street parking. In densely populated zones, the establishment of parking structures has been undertaken to ameliorate the acute parking challenges afflicting downtown areas. Additionally, traffic infrastructures are built to maintain a fluent and safe traffic environment, incorporating elements such as traffic lights, signs, and cameras. People's mobility patterns have also changed, for example automobile dependency, shared cars, traffic congestion becomes normal.

With the pervasive implementation of comprehensive public transit systems, an emergent urban development paradigm known as Transit-Oriented Development (TOD) has gained traction

within Asian cities, such as Kyoto, Hong Kong, and Singapore. This mode of development spurs mixed-use configurations and spatial densification in the vicinity of transit nodes. Moreover, the significance of parking facilities in proximity to transit stations is underscored, given that individuals often resort to private vehicles for the purpose of taking transit.

These are just a few examples of the urban-scale changes brought about by the advent of new transportation technology. This thesis will not delve further into these changes but will instead backtrack to predict the potential impacts of AVs on these aspects. Table 4.2 provides a comparison between the observed impacts of automobiles and the possible impacts of AVs at an urban scale. These impacts will be introduced in detail in the following paragraphs, one by one.

Urban Scale Impacts		Automobile	Autonomous Vehicle
Urban Form	Urban Pattern	<ul style="list-style-type: none"> • Suburban sprawl. • Downtown dense stratification. • Decline of urban core. • Muti-central urban structure. 	<ul style="list-style-type: none"> • Increased sprawl. • High density exurban islands served by AVs. • Urban transition towards densification and flattening. • Urban regeneration.
	Land Use	<ul style="list-style-type: none"> • Gentrification • Parking becoming one of the dominant land uses. 	<ul style="list-style-type: none"> • Decrease in parking land use. • More opportunity for non-motorized transportation and urban environment.
Mobility	Transportation System	<ul style="list-style-type: none"> • Hierarchy of urban road networks. • Traffic light and signal. • Hierarchy of transportation method. 	<ul style="list-style-type: none"> • Seamless transportation system. • Intelligent and connecting management systems.
	Mobility Pattern	<ul style="list-style-type: none"> • Automobile dependency. • Traffic congestion. • Automobile travel behavior. 	<ul style="list-style-type: none"> • Increase in vehicle miles travelled. • Thriving of massive public transit. • Decrease ion road capacity and traffic congestion.

Table 4. 2 Comparison Between the Observed Impacts of Automobiles with Possible Impacts of AVs.

4.1.1 *Urban Pattern*

It is widely acknowledged that the trajectory of urban expansion and the concomitant sprawl into suburban areas is often inevitable, particularly in North American cities, driven by the augmented efficiency afforded by Autonomous Vehicles (AVs) and concurrent population growth. However, this inexorable urban evolution is poised to be shaped by the heightened efficacy of traffic forecasting and vehicular interactions, leading to a discernible mitigation of traffic congestion and the potential emergence of fluid traffic conditions along AV transport corridors,

for example freeways which is allowed for AVs. As a result, urban growth may not follow the same even pattern as before, and areas surrounding AV transport corridors might experience faster growth compared to other regions. Moreover, there is the prospective formation of high-density exurban "islands", representing localized centers of intensified development situated at some distance from traditional urban cores.⁶⁹ (Figure 4.1)

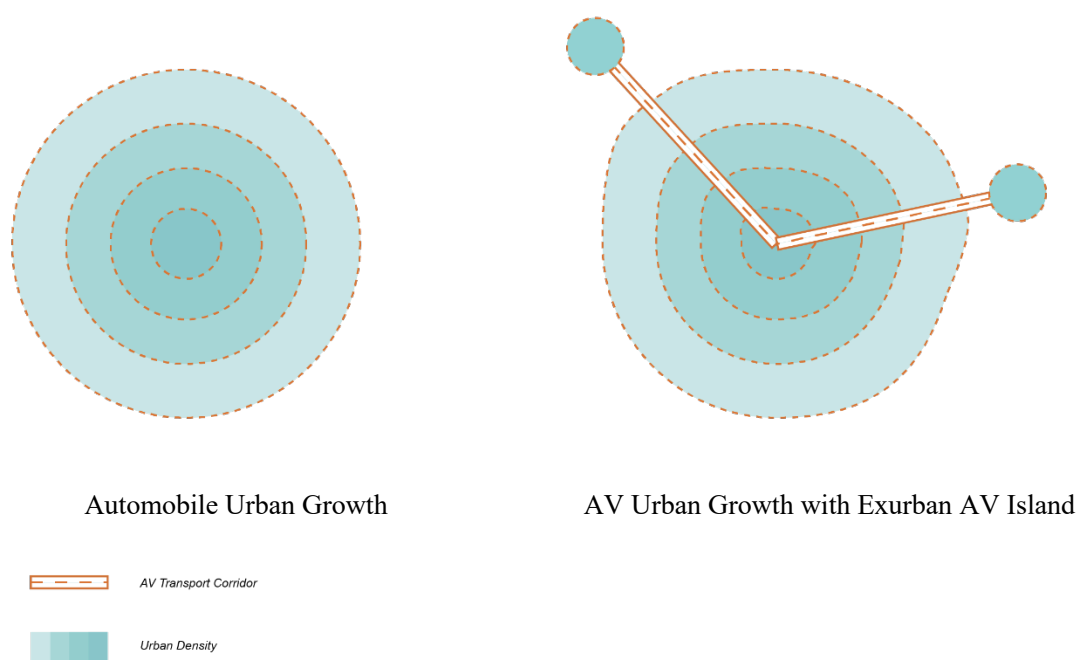


Figure 4. 1 Automobile Urban Growth vs. AV Urban Growth Pattern.

Redrawn version of original figure from Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*. Chapter 5.

As the urban perimeter expands, concomitant with this phenomenon, the density of the urban core will also increase. As previously discussed in this thesis, an ideal solution to mitigate endless suburban sprawl and the escalating ownership of cars is to make substantial investments in public transit and promote the advancement of Shared Autonomous Vehicles (SAVs). The crux of this approach pivots upon the fundamental premise that the seamless fusion of

⁶⁹ Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*.

convenience and efficiency, as offered by both transit systems and Shared AVs, will likely induce a substantial demographic inclination towards the adoption of SAVs for resolving the "last mile" predicament, while simultaneously favoring mass transit options for long-distance journeys. Consequently, Transit-Oriented Development (TOD) may emerge as a predominant urban development style in the future, resulting in denser areas near transit stations. Notably, the presence of SAVs could facilitate a more evenly distributed urban growth pattern in other areas, achieved through a more uniform distribution of people's mobility.⁷⁰ (Figure 4.2)

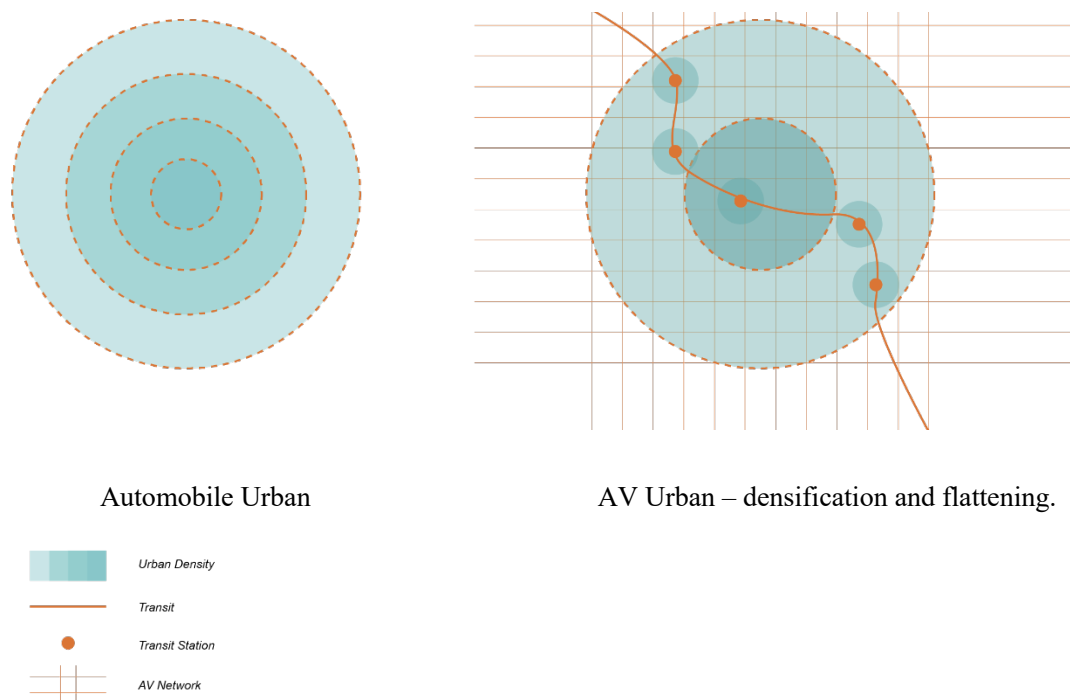


Figure 4. 2 Automobile Urban Pattern vs. AV Urban Pattern.

Redrawn version of original figure from Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*. Chapter 5.

⁷⁰ Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*.

4.1.2 *Land Use*

One of the most prominently impacted facets of land utilization resulting from the introduction of Autonomous Vehicles (AVs) is the domain of parking. In the previous section, this thesis discussed the inefficiency of current parking systems and highlighted some advantages of AVs in addressing these issues. For instance, in the current era, over 95% of a car's time is spent parked, with an average usage time of 1.5 – 2 hours.⁷¹ However, the implementation of AVs will greatly alleviate parking space constraints. AVs can navigate roads freely, find more distant parking spots, and utilize space more efficiently, in contrast to conventional automobiles, which cannot be parked too far away. In fact, when compared to the demand of 2 – 8 urban parking spaces per conventional automobile, autonomous vehicles only require 1 – 2 urban parking spaces per AV, and even just 1 parking space per Shared Autonomous Vehicle (SAV).⁷² Meyboom's estimates suggest that 1 shared AV can replace 8 -10 automobiles in an urban area.⁷³

As SAVs become predominant in cities, the need for daytime parking may decrease considerably, as SAVs can remain in motion for operation based on AI computation. However, the demand for parking might surge during the nighttime when SAV demand is lower. Consequently, the city could repurpose parking lots in shopping malls or other parking lots to store these SAVs.⁷⁴ Moreover, these parking facilities could be integrated with an energy grid to charge AVs while they are parked.

Simultaneously, the emergence of AVs will lead to a highly efficient utilization of roads and lanes, resulting in narrower roadways and potentially fewer traffic lanes. Gas stations and other

⁷¹ Rajasingham, D. (n.d.). "Driverless vehicles - Opportunities and challenges in new networked world," Commonwealth bank of Australia., August 14, 2016. <https://www.commbank.com.au/content/dam/caas/newsroom/docs/2016-08-16-CBA-driverless-cars-white-paper.pdf>

⁷² Jean-Paul Rodrigue, et al., *The Geography of Transport Systems*.

⁷³ Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*.

⁷⁴ Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*.

conventional car service facilities may no longer need prominent placements, as autonomous vehicles can independently drive to these locations when not in use. These reductions in transportation-related land use present numerous opportunities for urban planners to create a livable, pedestrian-friendly, and safe urban environment.

4.1.3 *Transportation System*

In order to transition into a driverless future, three key factors are necessary: electrification, connectivity, and automation. Regarding the future transportation system, maintaining connectivity between vehicles, road conditions, and an information cloud is of utmost importance. This section will discuss the future transportation system from three aspects: traffic management, road systems, and intelligent infrastructure.

Autonomous vehicles offer a new opportunity for traffic management to ensure a smooth, safe, and optimal traffic flow on the road. For instance, AI can gather data from on-road AVs to comprehensively understand instant traffic conditions throughout the city. Moreover, AI can intelligently regulate varying degrees of congestion or toll charges based on real-time data, thus steering AVs away from congested routes. Notably, the envisaged intelligent connectivity obviates the necessity for certain physical road infrastructure elements, as these are replaced by their virtual counterparts. The advent of Virtual Infrastructure introduces a dynamic element to traffic rules, such as speed limits during specific hours or days, the conversion between one-way and two-way roads, and regulations for the access of different vehicle types.⁷⁵

The present hierarchy of urban road systems can be simply classified into four levels: highways, arterials, collectors, and local streets. In a driverless future, this system will not change

⁷⁵ Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*.

significantly; these four levels of road hierarchy will remain. However, the traffic grid might become sparser (as depicted in Figure 4.6), as many local streets will be designed as mixed-use streets for various users. The impetus behind this shift is the emergent pedestrian trust in the ability of AVs to halt promptly, thereby prompting individuals to walk on the streets with greater confidence. Consequently, since the upper three levels of roads can address rapid and heavy traffic, local roads can be designed with a stronger focus on pedestrian and non-motorized transportation orientation, as will be detailed in the subsequent design section.

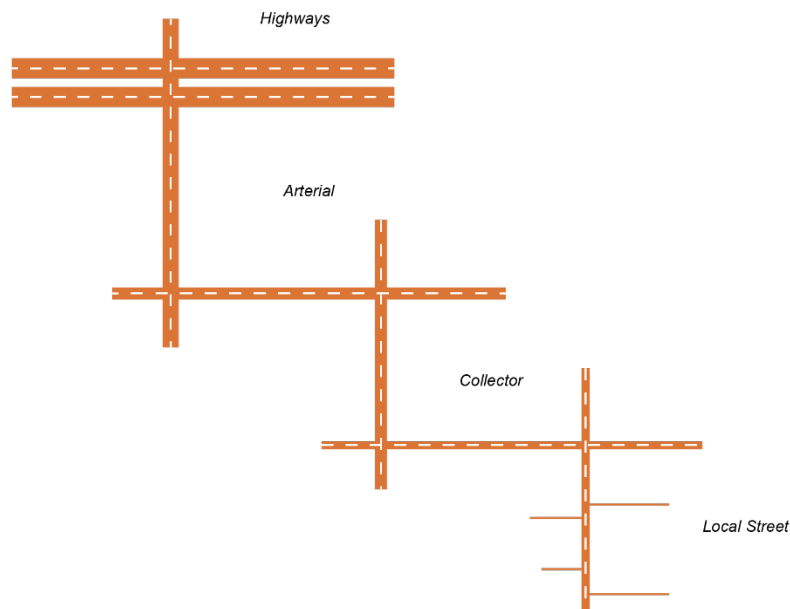


Figure 4. 3 Road Network Hierarchy.

Redrawn version of original figure from Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*. Chapter 5. Figure 5.5.

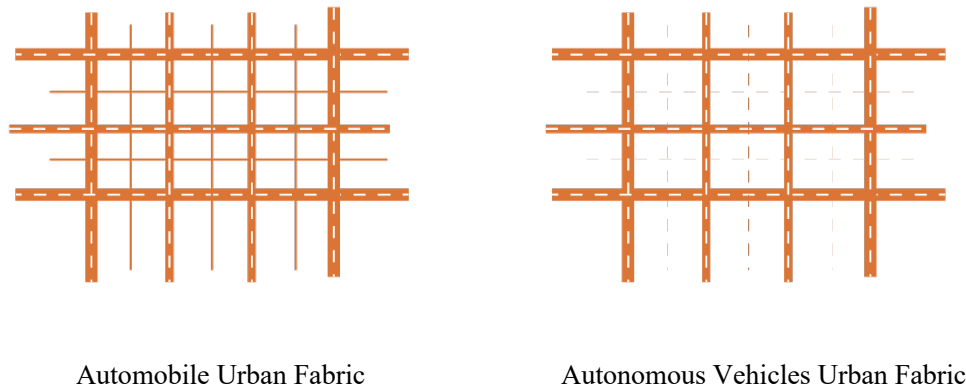


Figure 4. 4 Automobile Urban vs. AV Urban Fabric.

Intelligent infrastructure stands as one of the most crucial elements of realizing a driverless future for AVs. Even though the current Tesla can solely self-drive using its cameras and sensors without other infrastructures, constructing a multitude of intelligent infrastructures on the road is essential to maintaining a smooth and safe traffic flow. Through these infrastructures, AVs are endowed with the capability to engage in contextual communication with their surroundings, engendering an enhanced understanding of real-time conditions. Four types of interactions are required on the road for AVs: Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Infrastructure-to-Infrastructure (I2I), and interconnectivity with the overarching information cloud.⁷⁶

V2V interaction entails a sophisticated interplay between the internet, cameras, and sensors, enabling AVs to ascertain the contemporaneous speed, intentions, and conditions of fellow vehicles traversing the immediate vicinity. The V2I dimension underscores the exchange of information between AVs and the intelligent infrastructure, with a prime example being the receipt of traffic signal data.

⁷⁶ Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*.

Furthermore, I2I interaction confers the infrastructure with the capacity to discern the intentions of pedestrians or other non-motorized transit participants, consequently enabling the modification of traffic light sequencing, speed limits, and other relevant parameters to enhance safety and efficiency. For instance, a scenario could arise wherein a traffic light, detecting the absence of vehicles along one direction of a street, adjusts to consistently favor the alternate direction, thus optimizing traffic flow. The Information Cloud will collect and intelligently manage data to oversee traffic flow, as introduced previously.

4.1.4 *Mobility Pattern*

The mobility patterns of cities will be modified significantly with the widespread adoption of commercial Autonomous Vehicles (AVs), specifically Shared Autonomous Vehicles (SAVs). The transportation system in a driverless world will become more convenient, affordable, flexible, and seamless. In this autonomous era, the transportation ecosystem assumes a character of enhanced convenience and flexibility, rendering it an economically viable and practical choice for a diverse spectrum of travel needs. Given the cost-effectiveness and speed of mass rail transit, people will naturally gravitate towards using Shared Autonomous Vehicles (SAVs) to tackle last-mile challenges, while opting for rapid transit systems for long-distance travel. Leveraging the computational prowess of Artificial Intelligence (AI), individuals are empowered to embark on routes that optimize travel time, obviating prolonged waits for taxi or rideshare services. Upon arriving at transfer stations, SAVs will already be waiting, thereby obviating the wait time that often accompanies conventional transportation modes.

Figure 4.5 delineates a comparative representation between the current transit route and the envisaged Autonomous Vehicle (AV) transit route from point A to point B. Currently, individuals have to walk to the bus stop, take the bus to the rapid rail station, and then transfer. In a driverless

world, people could simply order a nearby bus to pick them up from home and take them directly to the rapid rail station.

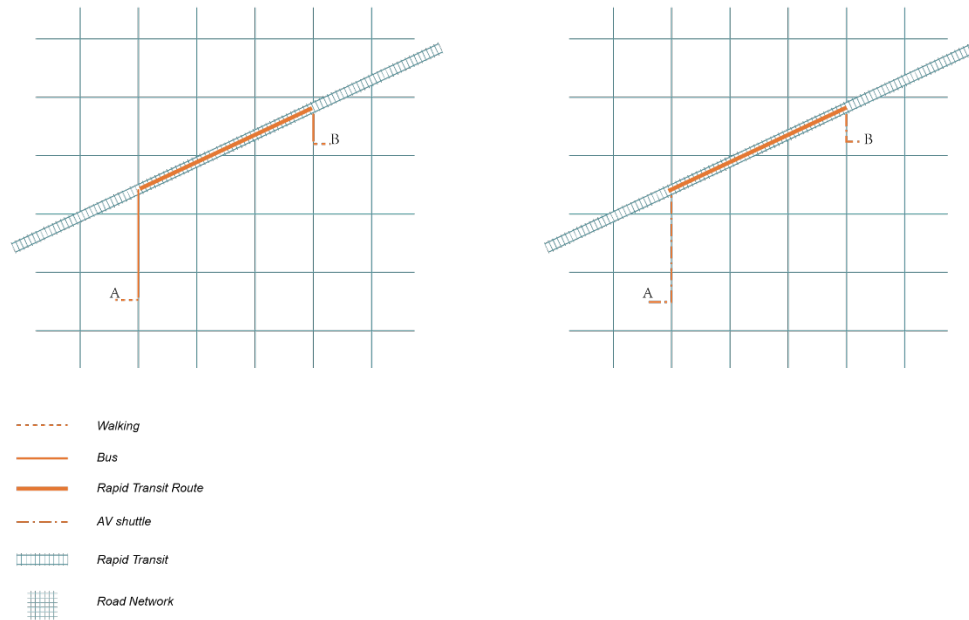


Figure 4. 5 Public Transit vs. AV Transit Movement.

Redrawn version of original figure from Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*. Chapter 5. Distributed Public: AV-Integrated Transit.

Figure 4.6 delineates a comparative representation between the current automobiles route and the envisaged Shared Autonomous Vehicle (SAV) route from point A to point B. For example, currently, individuals spend approximately 30 minutes driving automobiles to their destination. However, in a driverless future, people could choose to take AVs from point A to the rapid transit station, utilize rapid transit to reach the nearest station, and then resume the journey using AVs to point B. This option would require only 15 minutes, benefiting from the higher speed of rapid transit and seamless transfers.

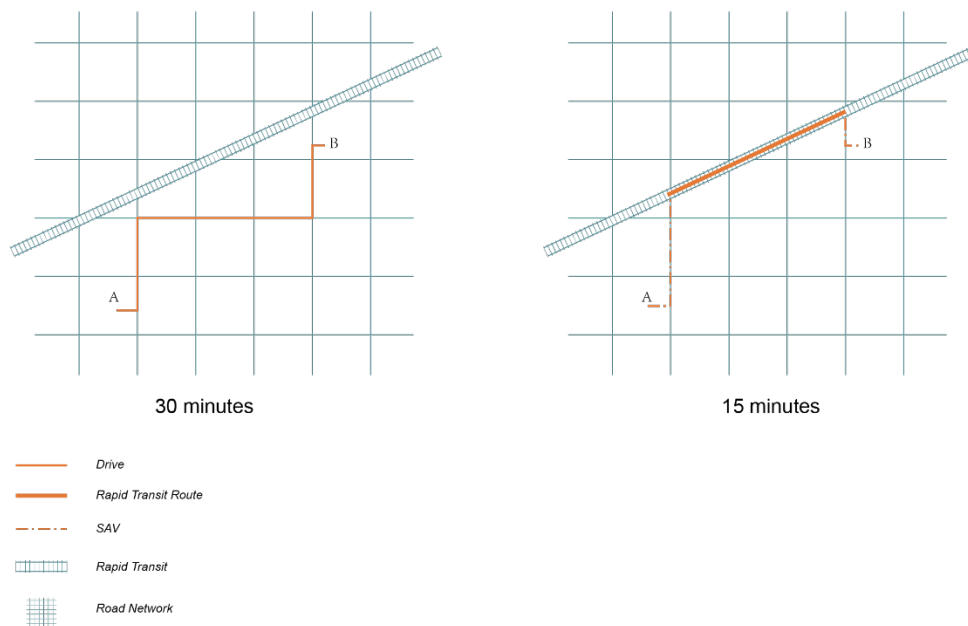


Figure 4. 6 Automobile vs. AV Movement.

SAVs will also create additional opportunities for life, work, and leisure activities. This impact will be particularly pronounced in North American cities where automobile dependency is exceptionally high. For example, during a road trip, people often need to search for parking spaces upon reaching their destinations. In contrast, SAVs will provide individuals with more flexible choices. (Figure 4.7)

in approximately 10 years.⁷⁷ However, it is often noted that such announcements tend to exaggerate improvements for marketing purposes, and it will need a period of time for individuals to replace their automobiles to autonomous vehicles even the technology is matured. As a result, this thesis adopts a more cautious approach, assuming that achieving a driverless world could take over 50 years.⁷⁸ This prediction is based on the assumption that, following the trajectory of previous vehicle technologies, autonomous vehicles will take one to three decades to dominate new vehicle sales and an additional one to two decades to dominate vehicle travel.⁷⁹ Thus, to arrive at a reasonable prediction for the realization of complete autonomous vehicles, this research opts for an average timeline of around 30 years for the emergence of fully developed autonomous driving technologies. Figure 4.8 illustrates a timeline depicting the maturity of vehicle technologies, providing insight into the technological development timeline towards a driverless future.

⁷⁷ Adela Spulber, Valerie Sathe Brugeman, Eric Paul Dennis, Zahra Bahrani Fard, "Future Cities: Navigating the New Era of Mobility." Center for Automotive Research, 2017. https://www.cargroup.org/wp-content/uploads/2017/10/Future-Cities_Navigating-the-New-Era-of-Mobility.pdf.

⁷⁸ Suzanne Hoadley, et al., "Road Vehicle Automation and Cities and Regions," Mobility & Traffic Efficiency, European Cities and Regions Networking for Innovative Transport Solutions., January 23, 2018. https://www.polisnetwork.eu/wp-content/uploads/2019/06/polis_discussion_paper_automated_vehicles.pdf.

⁷⁹ Todd Litman, "Autonomous Vehicle Implementation Predictions: Implications for Transport Planning," Victoria Transport Policy Institute, June 21, 2023. <https://www.vtqi.org/avjp.pdf>.

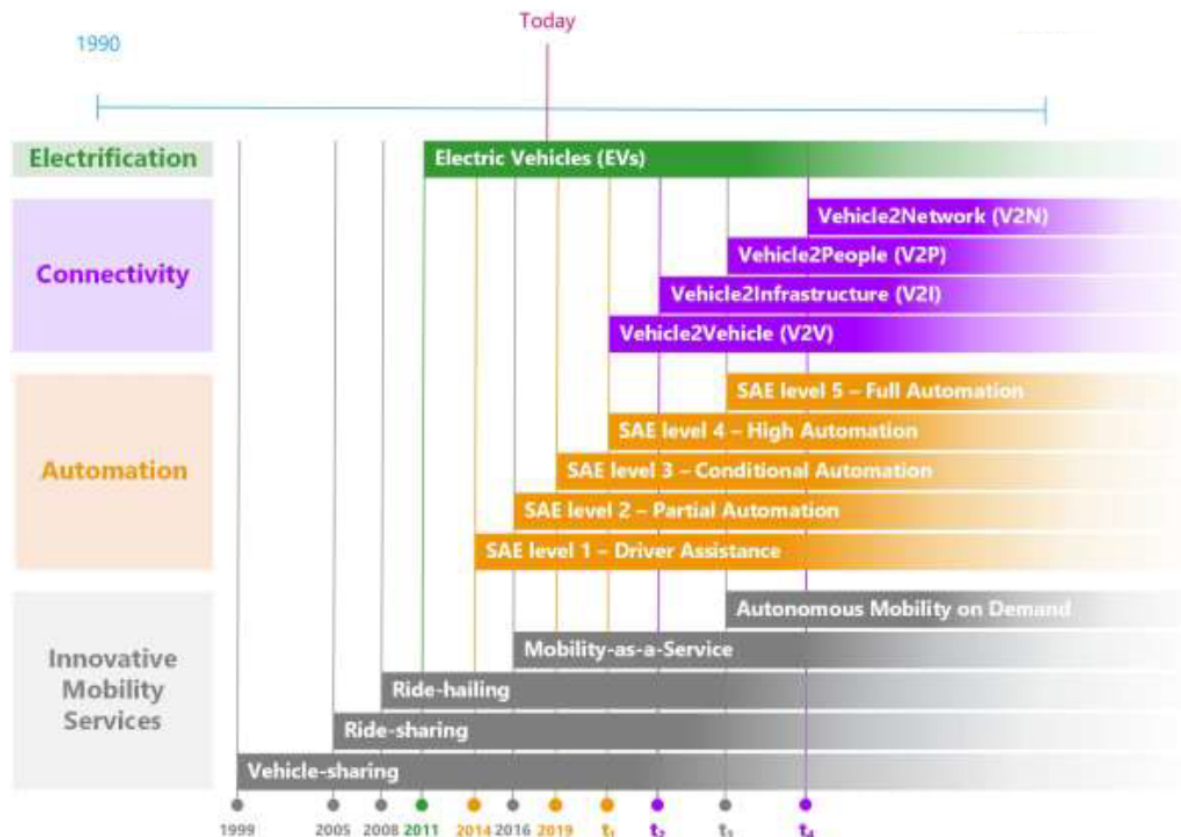


Figure 4. 8 Development Timeline of Vehicle Technologies and Mobility Services.

Source from Pierluigi Coppola, et al., " Autonomous Vehicles and Future Mobility,"

4.2.2 Development Phases

By combining the technology development timeline with Serio Agriesti's three-phase future prospect, this section will introduce a developmental pathway for the implementation of AVs without any interventions.⁸⁰

The research outlines Phase 1, which spans from the present to the future when autonomous driving technology reaches SAE Level 3. In this phase, car ownership will continue to rise, especially for human-driven vehicles, leading to a surge in vehicles on the road and inefficiencies in traffic flow.⁸¹ Consequently, road capacity will decrease, and congestion will worsen.

⁸⁰ Agriesti, et al., "Impact of Driverless Vehicles on Urban Environment and Future Mobility."

⁸¹ Agriesti, et al., "Impact of Driverless Vehicles on Urban Environment and Future Mobility."

Additionally, existing transportation issues will intensify, resulting in heightened traffic congestion in urban areas and on highways. Public transit ridership will remain steady, and suburbs will persistently expand until the endless commute times become intolerable.

Phase 2 involves the partial self-driving capability of autonomous vehicles, with some even reaching SAE Level 4 or 5. During this period, technological advancements in autonomous vehicles will alleviate traffic conditions on the road. Peripheral road congestion will decrease due to enhanced road capacity. However, owing to the allure of convenience and comfort provided by autonomous vehicles, an increasing number of people will opt to buy and use them. This surge in car ownership will exacerbate the issue, especially as a large number of disabled individuals gain access to driving. Consequently, urban traffic congestion will worsen.⁸² Downtown areas may experience decline due to deteriorating environments, while suburban areas will witness renewed growth owing to the enhanced efficiency of private AVs. The availability of cheaper private AV transportation options will lead to a decline in public transit ridership. The coexistence of human drivers and autonomous vehicles will raise the likelihood of traffic collisions, a situation that will only improve as the number of human drivers on the road decreases, thus increasing safety.

To address these challenges, the Mobility as a Service (MaaS) paradigm garners prominence as a panacea. While autonomous vehicles may free drivers from direct control, the true advantage lies in the blurring distinction between individual and public transit.⁸³ As this concept gains prominence and becomes mainstream, the city will transition into Phase 3. In this phase, city governments and local service providers seize the opportunity to offer convenient and affordable services. More investment in public transit to build a fast and comfort environment. Meanwhile, commercial AVs (CAVs) and Shared AVs (SAVs) will emerge as the primary solutions for last-

⁸² Agriesti, et al., "Impact of Driverless Vehicles on Urban Environment and Future Mobility."

⁸³ Michael Szell, Carlo Ratti, Paolo Santi. "Trip Sharing in the Era of Self-driving Cars." Marron Institute of Urban Management, August 31, 2015.

mile connections. Trip sharing could potentially reduce the required number of vehicles by up to 40%, and the widespread adoption of SAVs could amplify these savings.⁸⁴ Public transit will experience a revival. A significant portion of the population will choose public transit for long journeys and employ SAVs for the last mile. Enhanced intelligent services will enable seamless transfers. During this phase, traffic congestion will significantly diminish due to increased road capacity and a reduced number of vehicles on the road. City governments may repurpose transportation land, such as street parking and local streets, to enhance urban livability and sustainability. Downtown density will surge as more people opt for city center living due to convenience and a welcoming environment, rejuvenating the downtown area. Lastly, traffic accidents will drastically decrease, reaching minimal levels as all vehicles are under computer control. Table 4.3 presents a brief summary of the city changes during the three phases.

⁸⁴ Michael Szell, et al., "Trip Sharing in the Era of Self-driving Cars.

	Phase 1	Phase 2	Phase 3
Possible period	Present – 10 years	10 – 25 years	25 - 40 years
Induced demand	Congestion increases. Road capacity decreases, road area increases.	Congestion decreases in peripheral roads and increase in the city. VMT increases. Road capacity Increases.	Congestion is reduced in the whole city. VMT increases. Road capacity Increases. Road lanes and width decreases.
Public Transit	Ridership remains constant. Poor maintenance and investment.	Ridership decreases. Poor maintenance and investment	Ridership increases. Lots of Investment on public transit, pedestrian facility, and city environment, etc.
Social Impact	Private car ownership increases.	Private car ownership increases. Disabled and old people can own a car.	Private car ownership decreases. SAV and CAV become the majority choice for the last mile.
Pedestrian Safety	High risk of traffic accident. Pedestrian infrastructure remains poor.	The risk of traffic accident increases until only few drivers on the road.	Traffic accident possibility drastically decreases.
Density	Suburban sprawl increase. until people cannot tolerate the time for commuting. Then sprawl will stop.	Suburban sprawl again.	Downtown becomes denser. TOD improve the density and mixed-use surround transit stations. City become more flat

Table 4. 3 Summary of Effects in Different Phases.

4.2.3 *Transportation Development*

According to the aforementioned research on urban transformation, it becomes evident that while Phase 3 represents an enticing aspiration pursued by urban planners, Phase 2 could exacerbate some existing urban problems. Consequently, transportation development should be strategized to mitigate the adverse effects of Phase 2 and expedite the transition into Phase 3.

During Phase 2, the adverse impact of AVs primarily stems from people gravitating towards private AVs for their convenience and preferable environment. This trend results in a reduction of public transit ridership and subsequently lowers investment in public transit systems. Previous research reveals that comfort, convenience, and affordability are pivotal determinants of individuals' mode choices. Hence, early government investment in transit infrastructure to enhance its efficiency and comfort could lead to a swift increase in public transit ridership and a significant reduction in private vehicle ownership. The National League of Cities report projects the integration of driverless technology into public transit systems by 2030, contributing to the seamless evolution of transportation systems as public and private entities collaborate to establish comprehensive urban mobility solutions.⁸⁵ Furthermore, government policy direction inclines to mobility service providers like Uber or Lyft could prompt an expanded fleet of Shared Autonomous Vehicles (SAVs) on the roads, reducing private AV ownership due to the convenience and cost-effectiveness offered by these SAVs.

Another critical aspect of transportation development pertains to the road system. A gradual transition from roads solely designated for human-driven vehicles (HVs) to AV roads is necessary to accommodate AVs. In terms of these AV roads, infrastructures and road designs are important to interact with AVs. Some researchers propose an intermediate plan for the shift from an HVs

⁸⁵ "City of the Future: Technology & Mobility," National League of Cities, 2015. <https://www.nlc.org/resource/city-of-the-future-technology-mobility/>.

road system to an AV road system. Through the concept of patchwork urban design, they introduce the notion of designing AV-only zones under three key principles: enhancing accessibility, changing land use, and implementing zone divisions. In a practical application, they identify three high-traffic areas, predominantly commercial and business zones in the central area of Seoul, as AV-only zones aimed at alleviating traffic congestion. These patches allow only a select few roads for both HVs and AVs to cross for main traffic, while the majority restrict entry to AVs to ensure smooth and safe traffic flow. Circulation roads accommodating both AVs and HVs interconnect these patches (Figure 4.9).⁸⁶ This experimental approach could hold promise for urban planners tasked with city design during Phase 2.

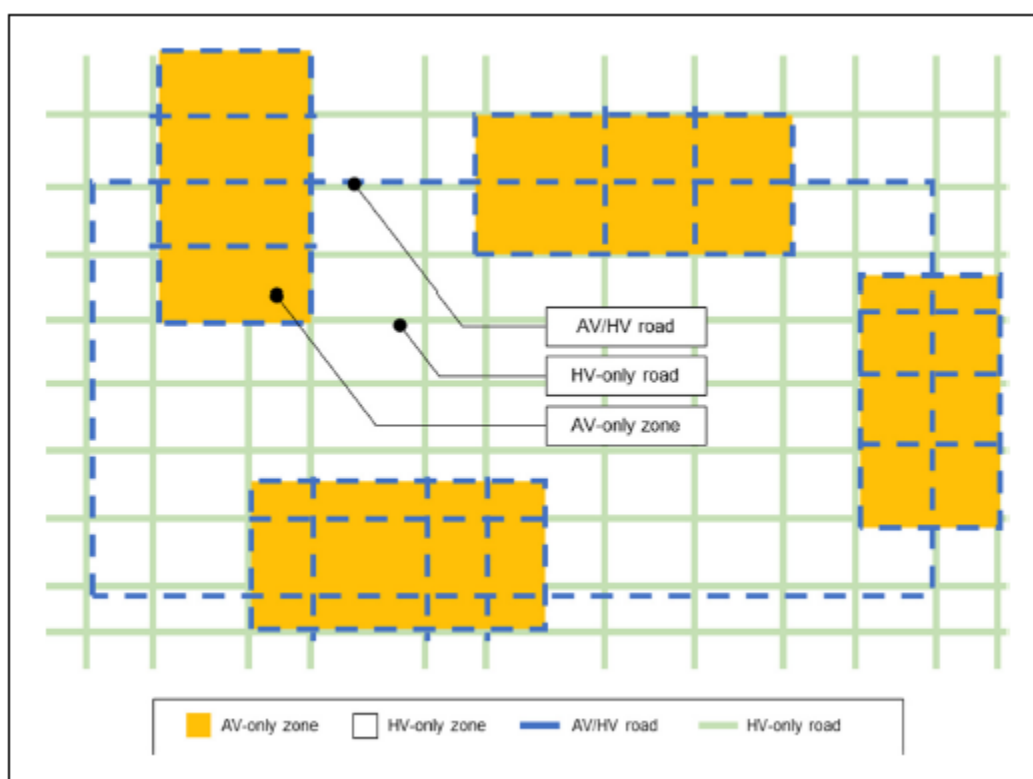


Figure 4. 9 Patchwork Concept to Plan and Design a City Considering AVs.

Source from Lee, Sunghee, et al., “Redesigning Urban Elements and Structures Considering Autonomous Vehicles: Preparing Design Strategies for Wide Implementation in Cities.” Fig. 8.

⁸⁶ Lee, Sunghee, et al., “Redesigning Urban Elements and Structures Considering Autonomous Vehicles: Preparing Design Strategies for Wide Implementation in Cities.”

4.2.4 SAV Operation Mode

According to the concept of mobility as a service (MaaS), the future number of operating SAVs will be determined by demand. To gain a deeper understanding of people's travel requirements, a brief simulation within an ideal city consisting of 100,000 residents and 25,000 Comprehensive Parking Plan (CPP) parking requirements. In this simulation, trips were generated using a traditional trip generation model, augmented by an additional 15% of trips as induced demand in the future.⁸⁷

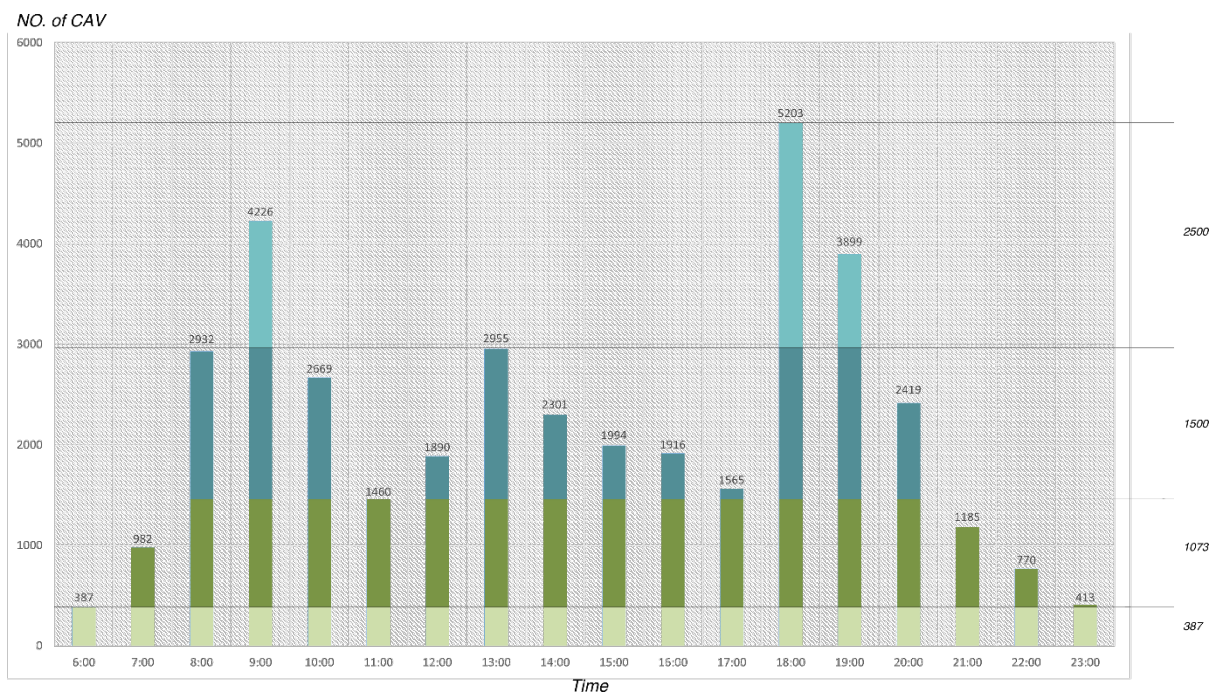


Figure 4. 10 Daily Vehicles Required to Meet the Demand of Trips During the Day.⁸⁸

Redrawn version of original figure from Agriesti, et al., "Impact of Driverless Vehicles on Urban Environment and Future Mobility." Figure 3

⁸⁷ Agriesti, et al., "Impact of Driverless Vehicles on Urban Environment and Future Mobility."

⁸⁸ Agriesti, et al., "Impact of Driverless Vehicles on Urban Environment and Future Mobility."

Figure 4.10 illustrates the simulated daily demand for vehicles within this city. In this simulation, the total number of Commenced AVs (CAVs) reaches 5,000 at peak times. According to the demand chart, approximately 387 CAVs are operational throughout the entire day, while around 1,073 fleets are active during daytime hours. Additionally, roughly 1,500 other vehicles are in use during peak hours and should be stored in nearby areas during their passive periods, with an additional 2,500 or more cars required exclusively during extreme peak hours.

This simulation categorizes operating CAVs into two main groups: active fleets and passive fleets. The active fleet encompasses the 387 vehicles that are in constant motion and may require parking only during the midnight period. The remaining 1,073 daytime fleets will park in designated parking lots or utilize street parking when not engaged in service. The passive fleet category comprises 1,500 CAVs that are exclusively needed during daily peak hours; these can be stored in nearby parking structures. Additionally, another 2,500 CAVs are intended for use solely during extreme peak hours and can be parked in more remote areas.⁸⁹ The distribution of these four fleet types is approximately 4:10:15:25, presenting a potential ratio for the operation of Shared Autonomous Vehicles (SAVs) within service companies.

⁸⁹ Agriesti, et al., "Impact of Driverless Vehicles on Urban Environment and Future Mobility."

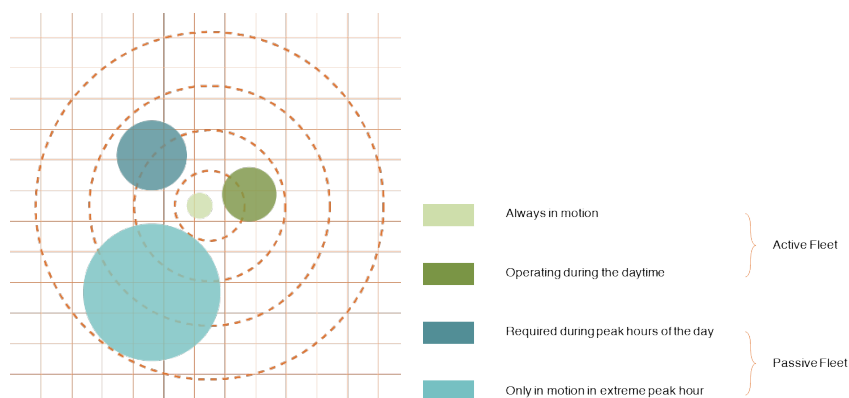


Figure 4. 11 CAV Distribution of the City.⁹⁰

Redrawn version of original figure from Agriesti, et al., “Impact of Driverless Vehicles on Urban Environment and Future Mobility.” Figure 4

4.2.5 Policy Pathway

Meanwhile, a paper outlines a policy pathway designed to guide the public sector in facilitating the diffusion of AVs. This pathway encompasses six themes aimed at creating a livable and pleasant urban environment: 1) Roads, 2) Traffic Volume Restrictions, 3) Parking, 4) Public Transit, 5) Sharing, and 6) Mobility.⁹¹ This research envisions a superblock model that redefines city mobility patterns by prioritizing people, sustainability, and livability. This model promotes pedestrian orientation and reduced vehicle reliance. Unlike previous superblocks, which United States planning has sought to avoid, this new superblock serves as a designated testing area to develop plans and implement policies for sustainability and livability, rather than solely acting as a physical barrier between different neighborhoods.

Phase 1: Setting the Foundation for a Driverless Future

During Phase 1, city administrators and urban planners will establish initial superblocks as a step towards a driverless world. Roads will be categorized into main and local roads based on their

⁹⁰ Agriesti, et al., “Impact of Driverless Vehicles on Urban Environment and Future Mobility.”

⁹¹ Vitale Brovarone, Elisabetta, Jacopo Scudellari, and Luca Staricco. “Planning the Transition to Autonomous Driving: A Policy Pathway Towards Urban Liveability.” *Cities* 108 (2021): 102996–. doi:10.1016/j.cities.2020.102996.

functions. Main roads will serve as major transportation arteries connecting each superblock, while local roads will facilitate internal circulation within superblocks. These local roads will discourage cut-through traffic through measures such as limited speed, frequent traffic direction changes, and traffic calming elements.⁹² This design aims to improve the quality of internal public spaces.

AV-only zones and hybrid zones will be designated within these superblocks for technology testing. City governments and urban planners will collaborate with high-tech companies to identify test areas, such as AV-only zones, where initial testing will occur. Meanwhile, the initial testing is conducted on well-equipped roads with the necessary infrastructure. The public transit system will be reorganized to align with the new urban layout. Light rail networks will connect each superblock for mass transportation demand, while buses will primarily serve within the superblocks. The transportation department may partner with high-tech companies to test autonomous buses within closed environments, serving as a preliminary step towards assessing autonomous vehicle technology and infrastructure within these superblocks.

The existing city mobility pattern should be modified to promote shared and public transportation methods. Within these superblocks, private vehicle usage should be restricted, which may involve increasing parking fees or implementing entrance charges. Simultaneously, shared and public transportation options, such as shared cars, bicycles, or walking, should be actively promoted and enhanced. Street parking spaces designated for private cars should be reduced to enhance the non-motorized transportation (NMT) environment and create more public spaces. Furthermore, new multi-story car parks should be constructed along main roads to encourage drivers to park their vehicles there and opt for other encouraged modes of transportation.

Phase 2: Autonomous Vehicles in Operation

⁹² Vitale Brovarone, et al., "Planning the Transition to Autonomous Driving: A Policy Pathway Towards Urban Liveability."

As autonomous vehicle infrastructure matures, Phase 2 sees the expansion of AV-only and hybrid zones throughout the entire superblock. The public transportation system becomes fully autonomous and integrates shared vehicles to reduce reliance on private cars within the superblocks. Incentives and campaigns will be implemented to promote shared, public, and non-motorized transportation methods.

During this phase, street parking will be further reduced as residents increasingly prefer walking or cycling within the superblock. Reduced parking spaces will be leveraged by landscape and urban designers to enhance health, well-being, and overall quality of life. Central restricted traffic zones will permit only private cars owned by superblock residents and shared cars to operate, while other private and cut-through traffic will be prohibited.

The previous multi-story car parks will be modified to provide smart autonomous parking systems and charging space for autonomous vehicles with new infrastructures.

Phase 3: Reaching the Driverless Vision

In Phase 3, the complete transformation of the entire city will be realized, culminating in the realization of the driverless vision. Autonomous vehicle infrastructure will be deployed across all city roads, with traffic seamlessly integrated into central control systems. Real-time AI management will optimize traffic flow, and shared services and public transit will operate fully autonomously, forming an integrated Mobility as a Service (MaaS) approach.

Investments in public transit and the development of intelligent, seamless transfers to Shared Autonomous Vehicles (SAVs) result in a significant shift in travel behavior. A large portion of the population opts for public transit for long-distance travel and SAVs for last-mile connections due to enhanced comfort and economic benefits. Private vehicle ownership substantially declines, and parking is primarily restricted to multi-story parking lots. Street

parking spaces are repurposed into pick-up/drop-off platforms, contributing to a more sustainable and livable urban environment.

This comprehensive policy pathway envisions a gradual and controlled transition toward a driverless future, focusing on sustainable urban development, reduced vehicle dependency, and enhanced quality of life for residents.

Phases	Themes	Number	Action	Type	Sector
1	1	1.1	Classify the roads (main roads, local roads) and identify the main thoroughfare networks and the superblocks	Policy	Mobility
		1.2	Identify target areas (AV-only zones and Hybrid zones) to conduct AV tests in real urban environment	Policy	Innovation
		1.3	Implement necessary infrastructures for testing	Technology	Innovation Telecommunications
		1.4	Ensure road maintenance for testing	Physical	Public Work
	2	2.1	Enhance limitations to private cars in the central restricted traffic zone	Policy	Mobility
	3	3.1	Reduce street parking spaces	Physical	Mobility
		3.2	Develop new transfer facilities	Physical	Mobility
		3.3	Build multi-story parking structures along the main road network	Physical	Mobility
	4	4.1	Encourage the use of public transit	Policy	Mobility
		4.2	Reorganize the public transit system	Policy	Mobility
		4.3	Promote automation tests on public transit	Policy	Innovation
	5	5.1	Encourage the use of sharing services	Policy	Mobility
		5.2	Enhance sharing services	Policy	Mobility
		5.3	Support the renewal of the car sharing fleet with new ADAS	Policy	Mobility Innovation
		5.4	Promote tests on SAVs in some certain areas	Policy	Innovation
	6	6.1	Promote active mobility	Policy	Mobility
		6.2	Develop cycling networks in the superblocks	Physical	Mobility Public Work
		6.3	Improve pedestrian environment	Physical	Mobility Public Work
		6.4	Improve livability and quality of public spaces in the superblocks (temporary tactical interventions)	Physical	Mobility Public Work

2	1	1.5	Complete the implementation of autonomous vehicles infrastructures in certain zones	Technology	Innovation Telecommunications	
		1.6	Implement autonomous vehicles infrastructures on other roads in the superblock	Physical	Mobility Public Work	
		1.7	Ensure maintenance of all the roads in the superblock	Physical	Mobility Public Work	
		1.8	Gradually expand AV-only zones and hybrid zones in the whole superblock	Policy	Innovation	
	2	2.2	Prohibit private non-residents' vehicles in the central restricted traffic zones	Policy	Mobility	
	3	3.4	Build new multi-story parking structures along the main road network	Physical	Mobility	
		3.5	Install autonomous vehicles infrastructure on the multi-story parking structures	Technology	Innovation Telecommunications	
	4	4.4	Encourage the use of public transit	Policy	Mobility	
		4.5	Promote autonomous trams and buses in the superblock	Policy	Mobility	
		4.6	Begin to integrate local public transit system and shared cars	Technology	Mobility Innovation	
	5	5.5	Promote the use of sharing services	Policy	Mobility	
		5.6	Encourage the use of AVs in sharing services	Policy	Mobility	
	6	6.5	Promote active mobility	Policy	Mobility	
		6.6	Replace temporary interventions by structural ones in redesigning public spaces of the superblocks once they are provided with V2I connection infrastructure	Physical	Mobility Public Work	
	3	1	1.9	Complete the implementation of autonomous vehicles infrastructures on all the roads in the superblock	Physical	Mobility Public Work
			1.10	Complete the transformation to a driverless city	Policy	Innovation
		2	2.3	Transform superblocks in restricted traffic zones where circulation of private non-residents' cars is prohibited	Policy	Mobility
		3	3.6	Combine previous multi-story parking structures with intelligent and electric	Physical	Mobility Public Work

		infrastructure for autonomous vehicles		
	3.7	Eliminate all the on-street parking spaces	Physical	Mobility Public Work
	3.8	Build pick-up/drop-off platforms	Physical	Mobility Public Work
4	4.7	Promote the use of public transit	Policy	Mobility
	4.8	Encourage autonomous vehicles as the main last mile transportation methods	Policy	Mobility
	4.9	Integrate public transit and SAVs in a MaaS system on the transportation network	Policy	Mobility
5	5.7	Promote the use of sharing services	Policy	Mobility
6	6.7	Promote active mobility	Policy	Mobility
	6.8	Reorganize and design streets and public spaces to improve livability and the quality of the city	Physical	Mobility Public Work

Table 4. 4 The Action for the Sustainable Urban Mobility Plan.⁹³

Redrawn version of original table from Vitale Brovarone, et al., “Planning the Transition to Autonomous Driving: A Policy Pathway Towards Urban Liveability.” Table 1. Table 2. Table 3.

⁹³ Vitale Brovarone, et al., “Planning the Transition to Autonomous Driving: A Policy Pathway Towards Urban Liveability.”

Chapter 5. Design

Throughout the past century, automobiles have had a significantly detrimental impact on the public attributes of streets, resulting in a hazardous, polluted, and unwelcoming environment for pedestrians—a challenge that urban planners have long grappled with. With the advent of AVs, as discussed earlier, road capacity is expected to increase and transportation land use may decrease, presenting numerous opportunities for designing pedestrian-friendly, safe, and conducive streets. This section will present ideas for street design in an optimistic driverless future and will employ Belltown as a case study to illustrate how the present city can be transformed into a driverless city.

5.1 Urban Elements Design

First, this section will illustrate some design ideas for the future driverless city. This part will be divided into 4 aspects: road types, street design, parking lots, and shipping.

5.1.1 *Road Types*

The following six pictures show illustrations of AV roads. Figure 5.1 depicts a possible future for downtown business or commercial streets with a wide central public space in the middle of the street due to reduced drive lanes. Figures 5.2 and 5.3 show this street with public transit. Since the transportation system will be seamless, transfer/pick-up/drop-off islands between light rail and drive lanes are important and will not disrupt the flow of non-motorized transportation. Figures 5.4 and 5.5 display retail streets of varying widths with public spaces on both sides. These streets will provide spaces for people to play, sit, or eat, creating an active atmosphere on the street. A greater number of people on the street will improve the pedestrian environment, attract more visitors, and reduce the potential for crime. Figure 6 illustrates a

residential street where the driving lanes will be much more shared for different uses. Car speeds will be limited, creating a safe and vibrant street life.



Figure 5. 1 100' Width Street.



Figure 5. 2 100' Width Street with Transit.

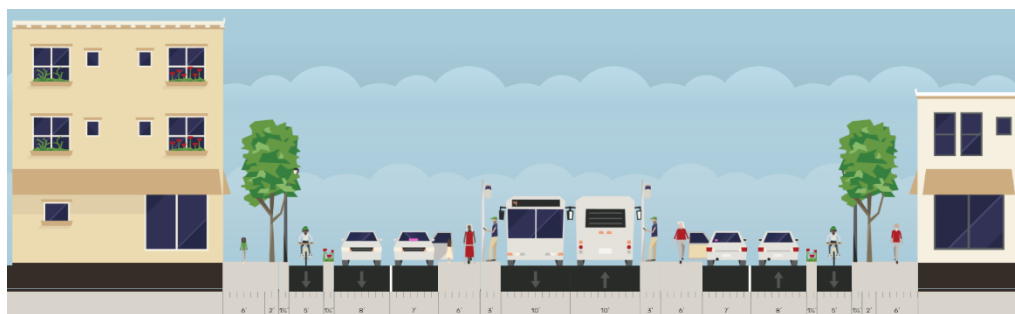


Figure 5. 3 100' Width Street with Bus.

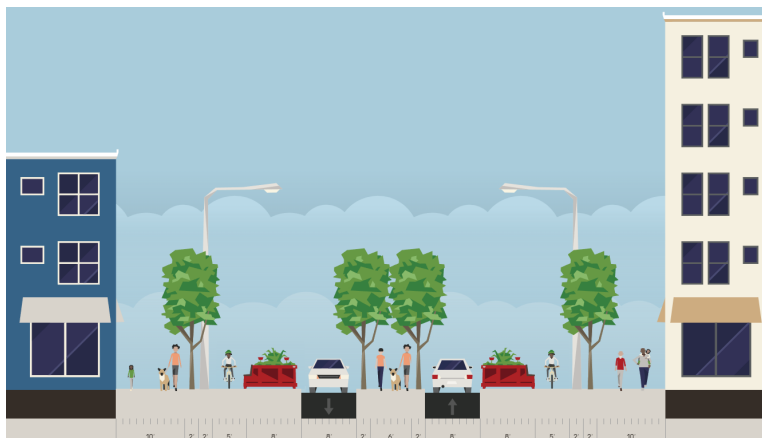


Figure 5.4 80' Width Street.



Figure 5.5 50' Width Street.



Figure 5.6 50' Width Residential Street.

Redrawn version of original figure from Lee, Sunghee, et al., "Redesigning Urban Elements and Structures Considering Autonomous Vehicles: Preparing Design Strategies for Wide Implementation in Cities." Fig. 2.

5.1.2 *Street Design*

Discussing street design, two types of street surface prototypes are considered: Efficient Surface (Figure 5.5) and Shared Surface (Figure 5.6), which can be utilized in different conditions.⁹⁴

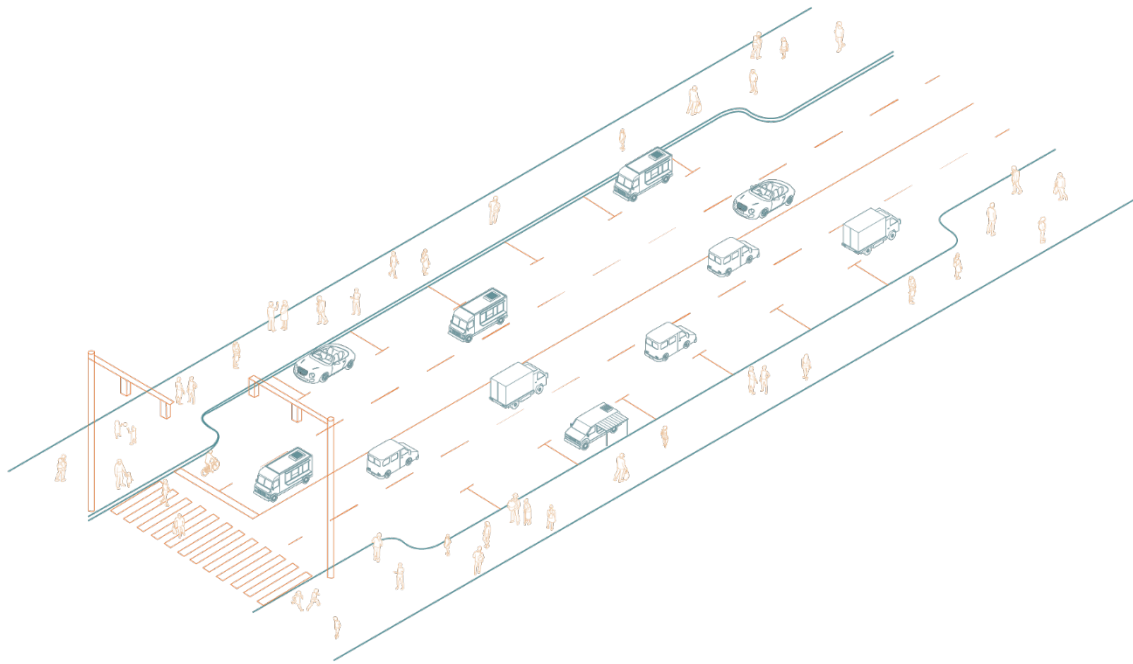


Figure 5. 7 Efficient Surface.

Redrawn version of original figure from Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*. Chapter 7. Flat Street.

⁹⁴ Zhang, Daya. "Rethinking streets: urban life with autonomous vehicles." S.M. Massachusetts Institute of Technology, 2018.

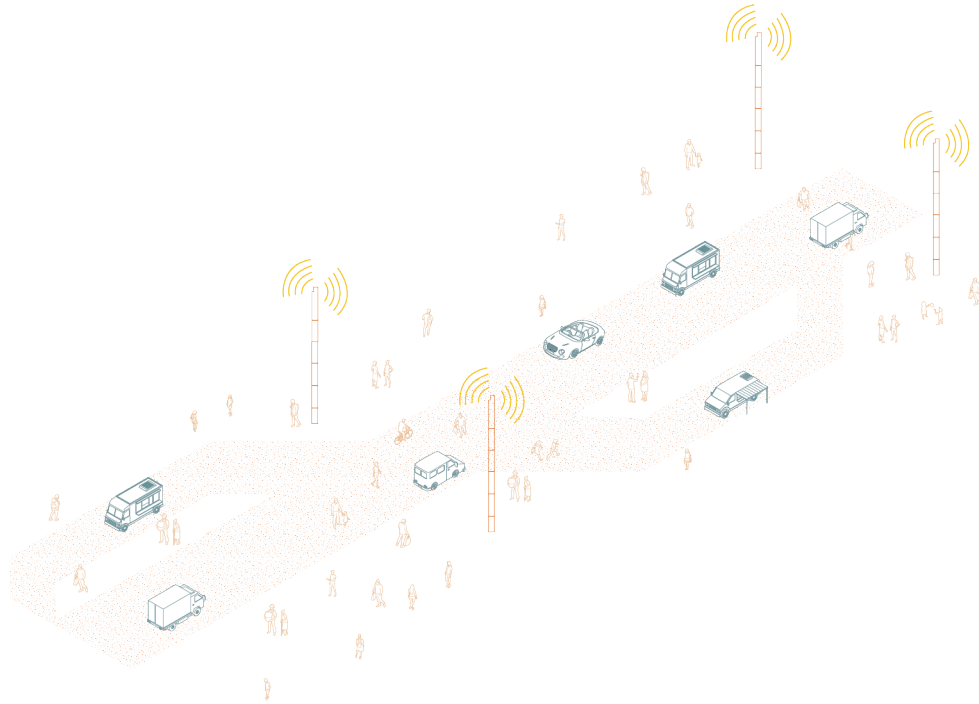


Figure 5. 8 Shared Surface.

Redrawn version of original figure from Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*. Chapter 7. Flat Street.

Efficient surface provides dedicated areas for AVs, buses, and shuttles to deliver a great number of people at a faster speed. With dedicated driving areas (Figure 5.7), AVs could drive at a faster speed to connect important nodes (like hospitals, school, museum, city center, etc.), residential areas, and people's workplaces. This type of surface should be used on arterials, connectors, and some important local roads.

The merit of a shared surface (Figure 5.8) is to create a comfortable pedestrian and vibrant environment with lower speed on this surface. All the shared surfaces are defaulted to be commonly used by pedestrians, cyclists, shuttles, and vehicles. The speed of AVs will be limited to 3 mph when people are around and 20 mph when it is safe to do so. This type of surface could be used on local roads to create a leisurely and healthy environment due to lower traffic noise

and speed. Moreover, shared surfaces will also improve the profits of retailers since it is more pedestrian-oriented, providing more opportunities for them.

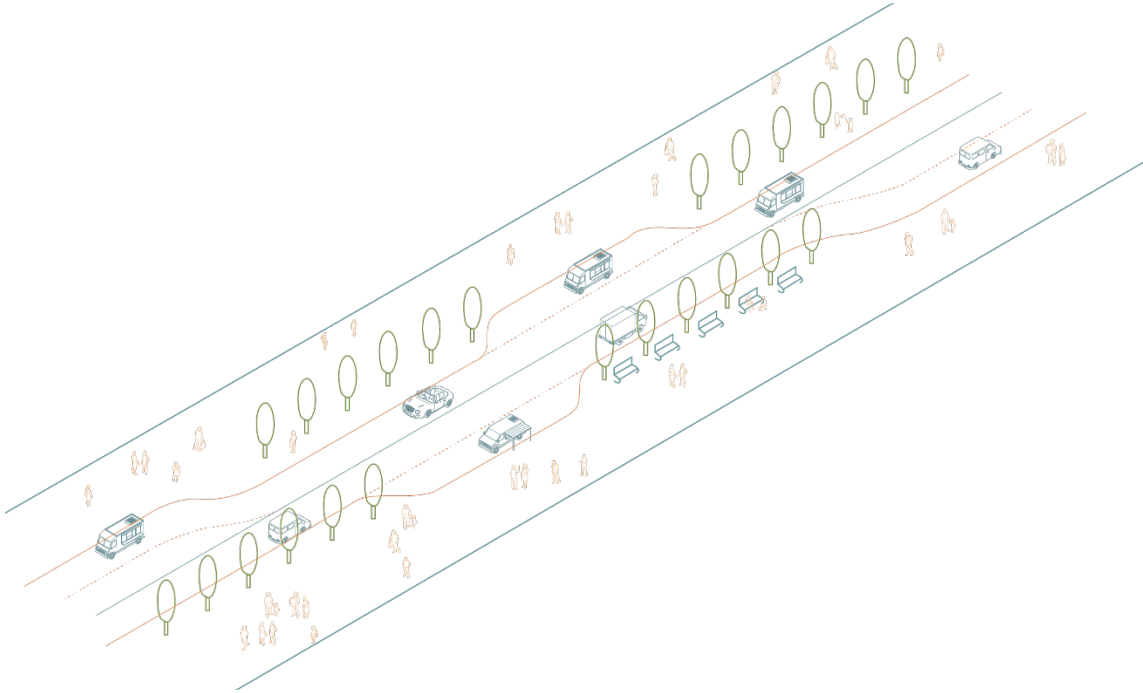


Figure 5. 9 Street Reallocated to Walking Boulevard on Perimeter.

Redrawn version of original figure from Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*. Chapter 7. Reclaim the Boulevard: Edge

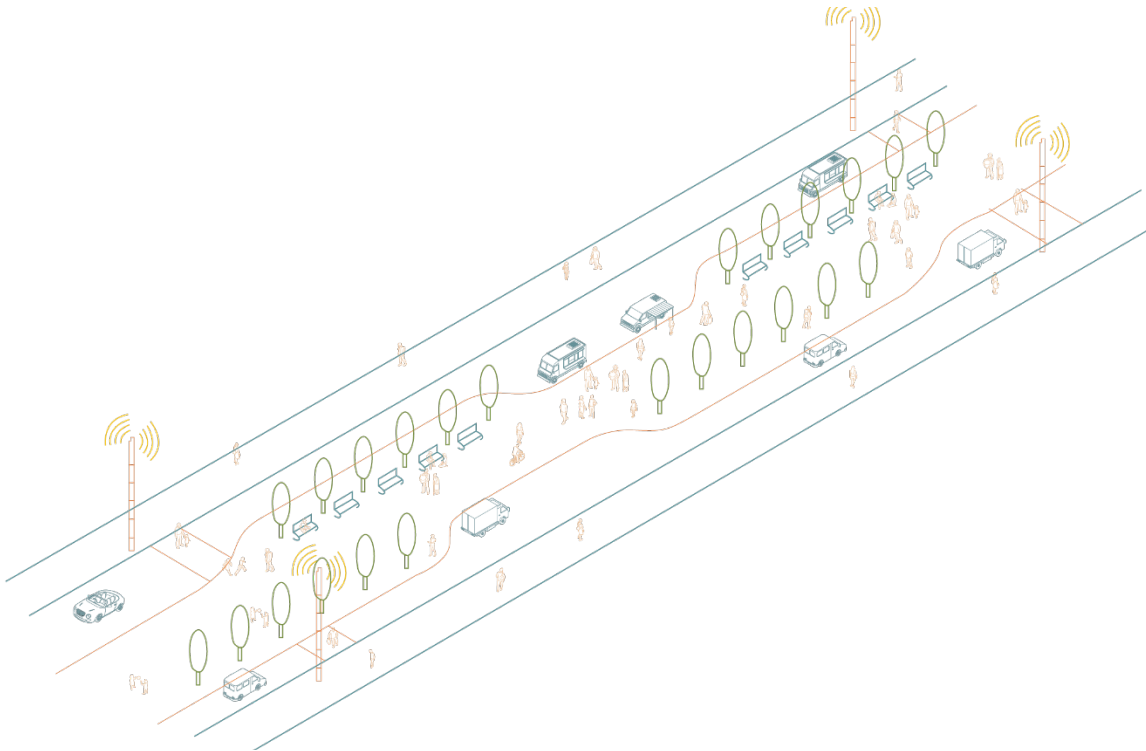


Figure 5. 10 Street Reallocated to Walking Boulevard in Center.⁹⁵

Redrawn version of original figure from Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*. Chapter 7. Reclaim the Boulevard: Centre

As previously mentioned in this research, the advent of autonomous vehicles will create opportunities to reclaim more areas from cars, providing additional spaces for pedestrians, cyclists, and other non-motorized transportation groups. Optimistically, some believe that two lanes are sufficient for a two-way road (one lane for each direction). Furthermore, Gehl asserts that three-lane roads do not exhibit higher efficiency compared to one-lane roads with effective turning lanes where turns are permitted.⁹⁶ AVs are expected to enhance the efficient use of roads. It is anticipated that AVs will enhance the efficient utilization of roads. Therefore, this paper

⁹⁵ Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*.

⁹⁶ Gehl, Jan. *Cities for People*. Washington, DC: Island Press, 2010.

proposes two lanes are enough for a driverless world, thus, it will leave some areas for pedestrians.

Metz presents two options for utilizing these areas: Street reallocated to a walking boulevard on the perimeter (Figure 5.9) and Street reallocated to a walking boulevard in the center (Figure 5.10).⁹⁷ If the street is reallocated to the perimeter, sidewalks will be wider, which is beneficial for adjacent retailers. Additionally, there will be ample space for transportation facilities, such as charging portals, bicycle racks, and shared bike stations. On the other hand, reallocating the street to a walking boulevard in the center creates a park-like space for walking and leisure in the middle. This division serves to separate passersby from those seeking leisure activities. Moreover, it establishes a designated drop-off and pick-up zone for transportation transfers, enhancing sidewalk functionality and reducing congestion.

⁹⁷ Metz, B, et al., *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*.

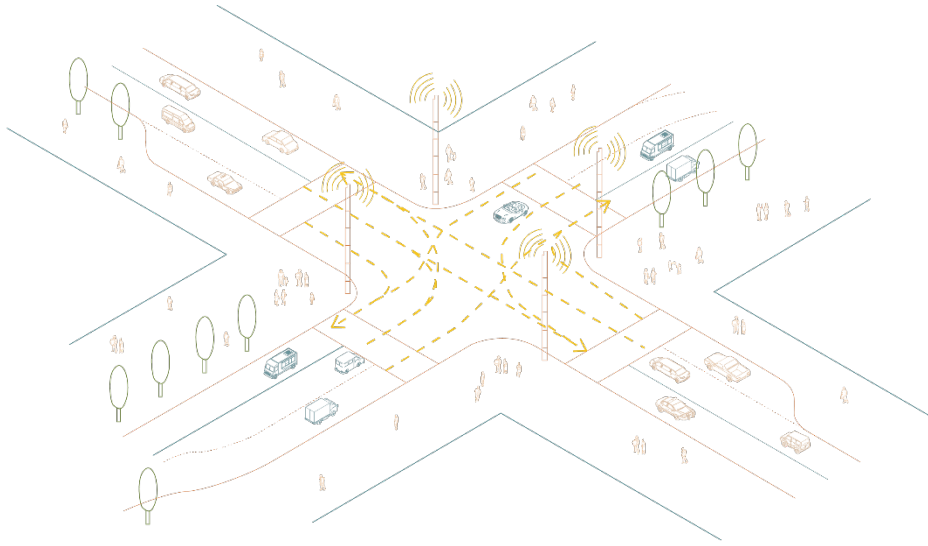


Figure 5. 11 Mobility Pattern at Intersection.⁹⁸

Redrawn version of original figure from Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*. Chapter 7. Lane allocation by vehicle speed.

⁹⁸ Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*.

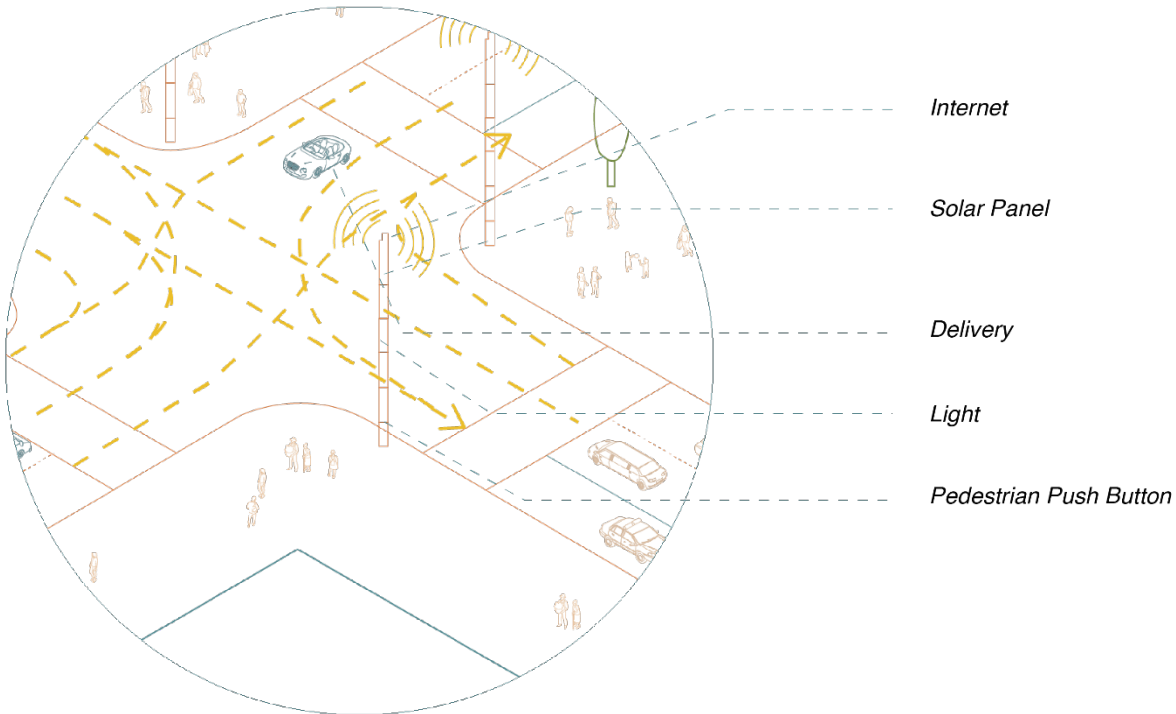


Figure 5. 12 AV Intersection Consisting of Multi-Functional Traffic Beacons.⁹⁹

Redrawn version of original figure from Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*. Chapter 7. AV intersection consisting of multi -functional traffic beacons.

Figure 5.11 illustrates the new traffic flow at the intersection of autonomous vehicle roads, where traditional traffic lights could potentially be replaced by a multifunctional traffic beacon. Figure 5.12 demonstrates several functions of this beacon, including directing traffic smoothly, communicating with vehicles and cloud information systems. The beacon could also interact with other road facilities, such as cameras and sensors, to gain a comprehensive understanding of the instant conditions at the intersection.

⁹⁹ Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*.

5.1.3 *Parking Lot*

As discussed earlier in this thesis, parking lots will undergo radical transformations in a driverless world. This section will present specific design concepts that illustrate the anticipated changes in these parking facilities.

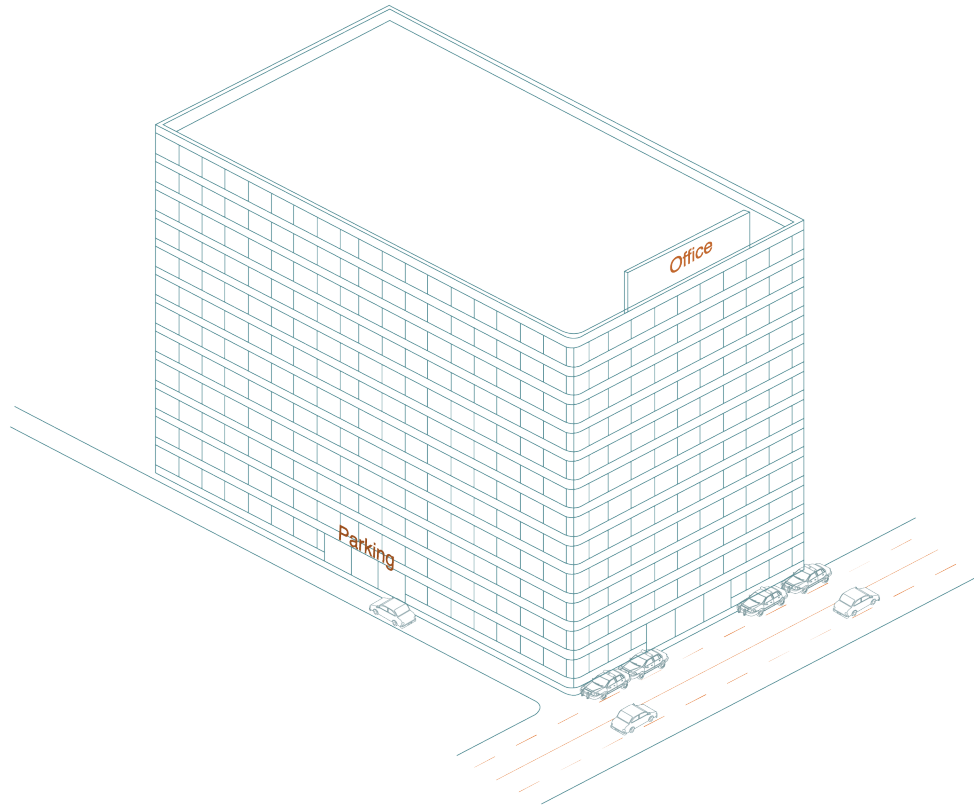


Figure 5. 13 Office Parking in the Present.

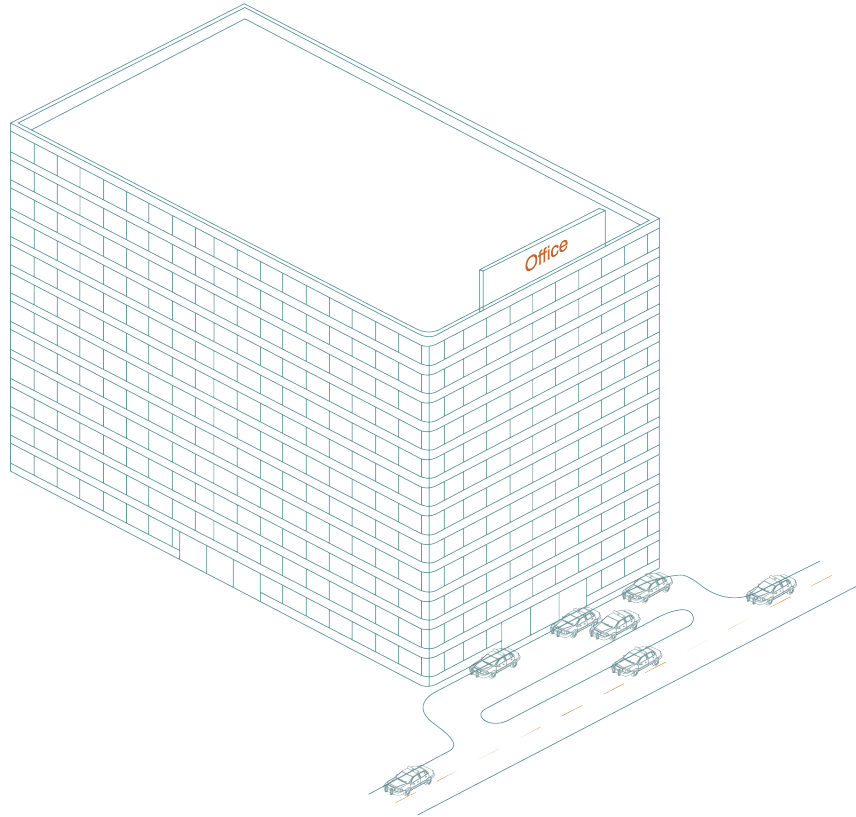


Figure 5. 14 Office Parking in the Future.

Figures 5.13 and 5.14 illustrate the anticipated changes in office parking arrangements for the future. Currently, employees' vehicles can park in the building's underground parking lot, while pick-up or drop-off vehicles may temporarily park on the side of the street. In the future, the office will require only a circulation road for pick-up or drop-off purposes, as autonomous vehicles can self-navigate to a slightly more distant parking lot. When individuals need vehicles, they can pre-order them, and they can just wait for AVs few minutes at the designated pick-up point.

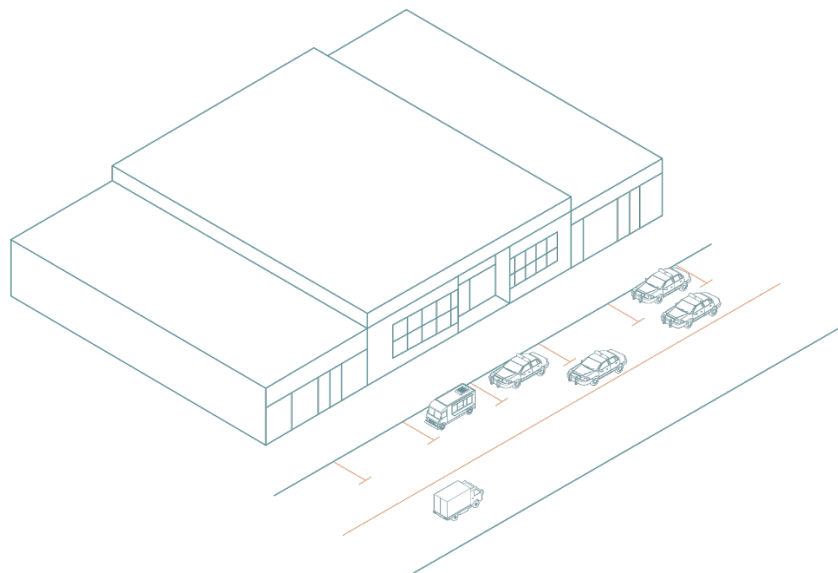


Figure 5. 15 Grocery Store Parking in the Present.

Redrawn version of original figure from Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*. Chapter 7.

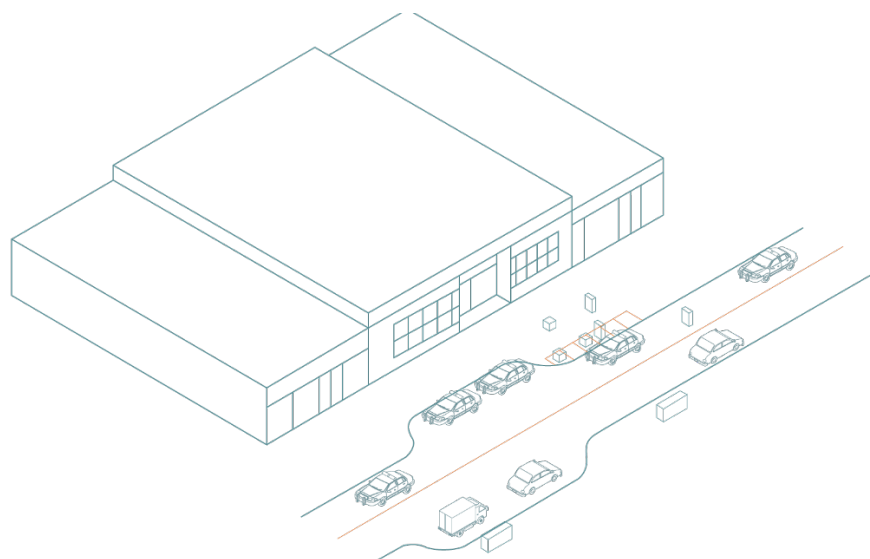


Figure 5. 16 Grocery Store Parking in the Future.¹⁰⁰

Redrawn version of original figure from Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*. Chapter 7.

¹⁰⁰ Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*.

Figures 5.15 and 5.16 illustrate the anticipated parking changes in retail stores. Presently, street parking and parking lots are commonplace features among retail stores in North America. Finding a parking space, particularly on busy streets, often consumes a significant amount of time. However, in a driverless world, retail establishments will require only designated pick-up or drop-off points for vehicles, similar to the office parking scenario mentioned earlier.

Furthermore, advancements in automation technology could lead to increased shopping efficiency through the use of drones and robots. Shoppers can pre-select their desired items either before or during their trip to the retail store. Upon arrival, drones or robots can seamlessly deliver the selected items to the curbside. Shoppers can then conveniently retrieve their items by simply opening the door.

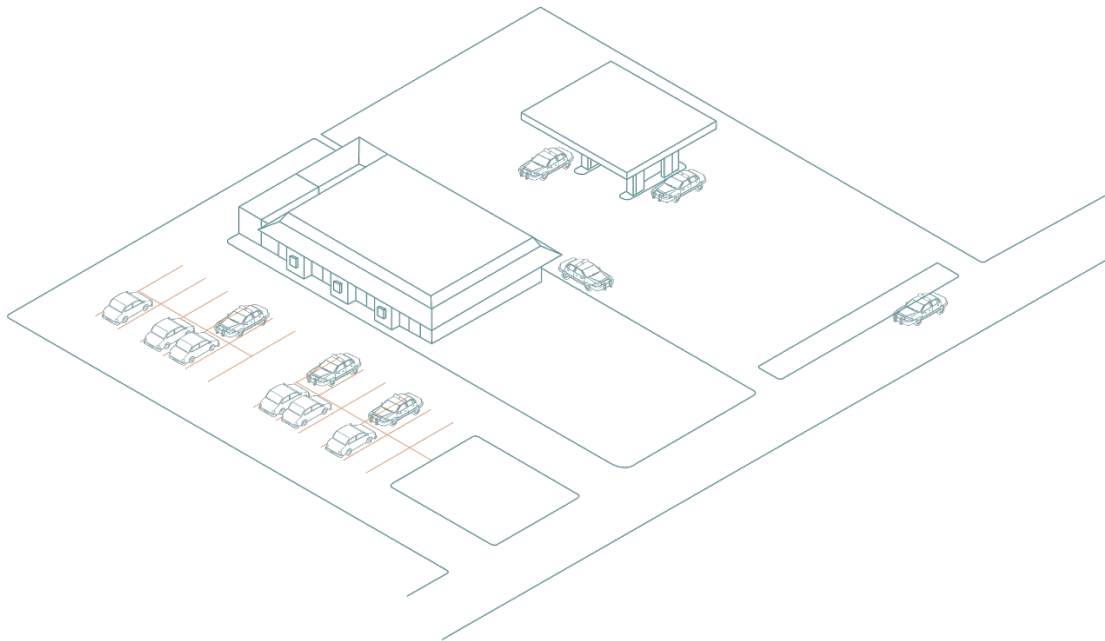


Figure 5. 17 Fast-Food Parking in the Present.

Redrawn version of original figure from Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*. Chapter 7. Typical gas station and drive-in restaurant.

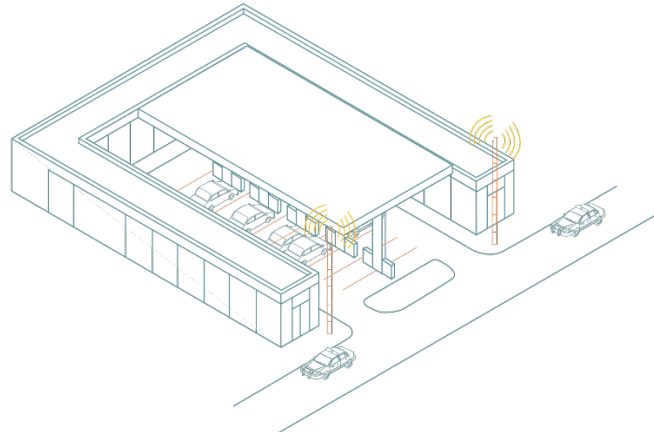


Figure 5. 18 Fast-Food Parking in the Future.¹⁰¹

Redrawn version of original figure from Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*. Chapter 7. Fast-charging station combined with fast-food service.

Meyboom also presents a potential design for fast-food parking in the future.¹⁰² Figure 5.17 depicts a typical layout for fast-food parking commonly found in North America, where drive-in and parking areas are separate, resulting in a significant land footprint. However, in the future, customers will have the convenience of ordering their food during their trip to the fast-food establishment and picking it up automatically (Figure 5.18), similar to the retail scenario described earlier.

Furthermore, Fast-food parking lot could also be integrated with a power grid.¹⁰³ This innovative concept allows individuals to park their vehicles in the fast-food parking area for rapid charging while they visit the fast-food establishment to enjoy a meal. This dual-purpose approach not only facilitates efficient vehicle charging but also contributes to the viability and success of these retail outlets.

¹⁰¹ Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*.

¹⁰² Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*.

¹⁰³ Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*.

5.1.4 *Shipping*

Recently, the delivery service has undergone substantial modifications, and these changes are anticipated to continue evolving in a driverless future. Retailers will swiftly enhance the efficiency of their delivery systems since consumer demand is heavily influenced by the speed of delivery methods. Loading, delivery, and even vending trucks are poised to be replaced by driverless vehicles, offering both cost-effectiveness and high efficiency.

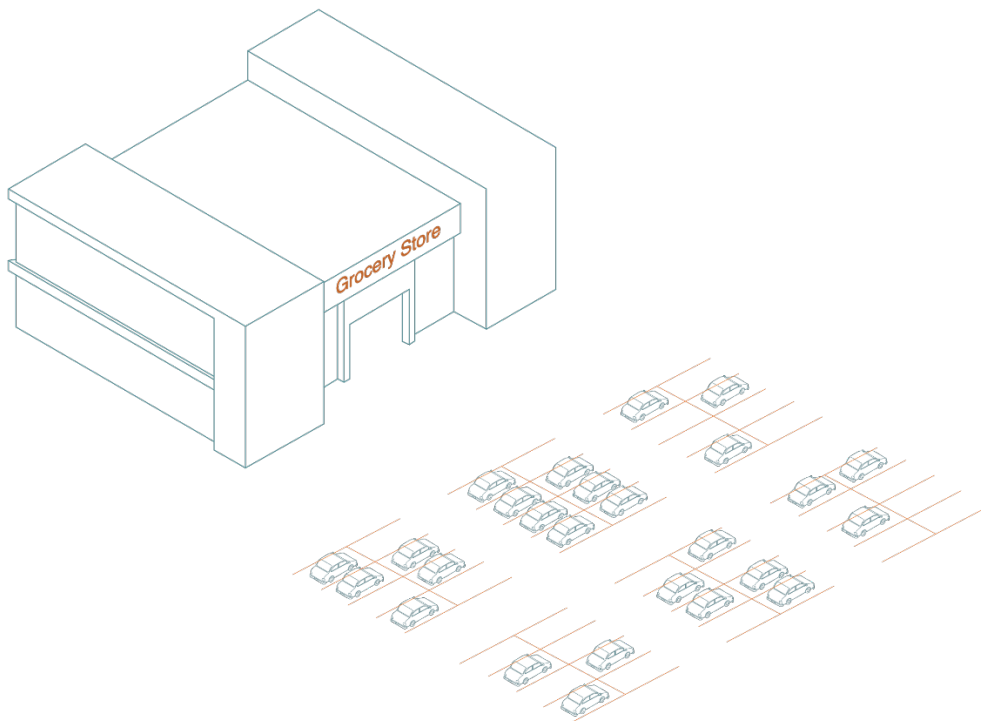


Figure 5. 19 Grocery Store Delivery in the Present.

Redrawn version of original figure from Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*. Chapter 7. Grocery dispatch hub with automated goods loading from freight trucks and into consumer vehicles.

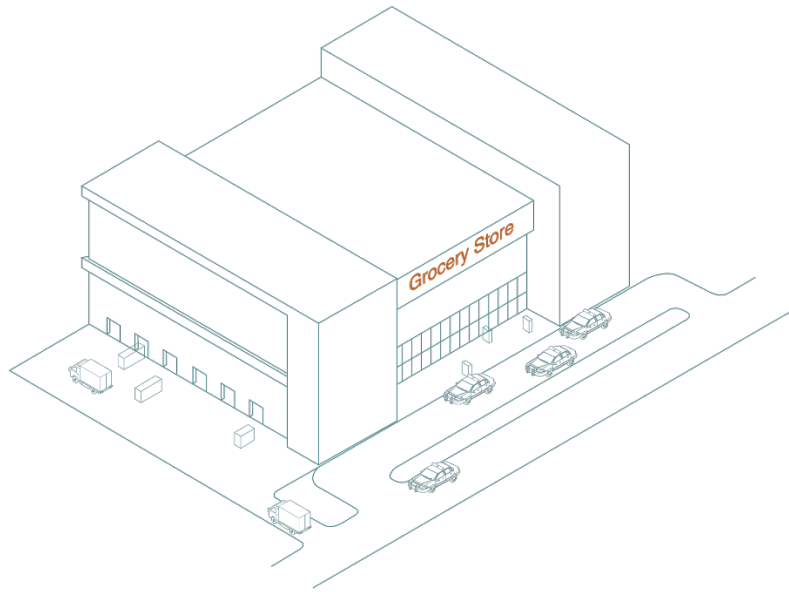


Figure 5. 20 Grocery Store Delivery in the Future.¹⁰⁴

Redrawn version of original figure from Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*. Chapter 7. Grocery dispatch hub with automated goods loading from freight trucks and into consumer vehicles.

Figures 5.19 and 5.20 illustrate possible changes for grocery stores. Currently, grocery stores require substantial land allocation for parking lots. However, in the future, the delivery system will be automated and driverless, rendering parking lots unnecessary. AI will intelligently plan routes for various vehicles to pick up items from grocery stores. This innovation will allow grocery stores to be situated away from high-density areas, resulting in substantial cost savings.

¹⁰⁴ Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*.

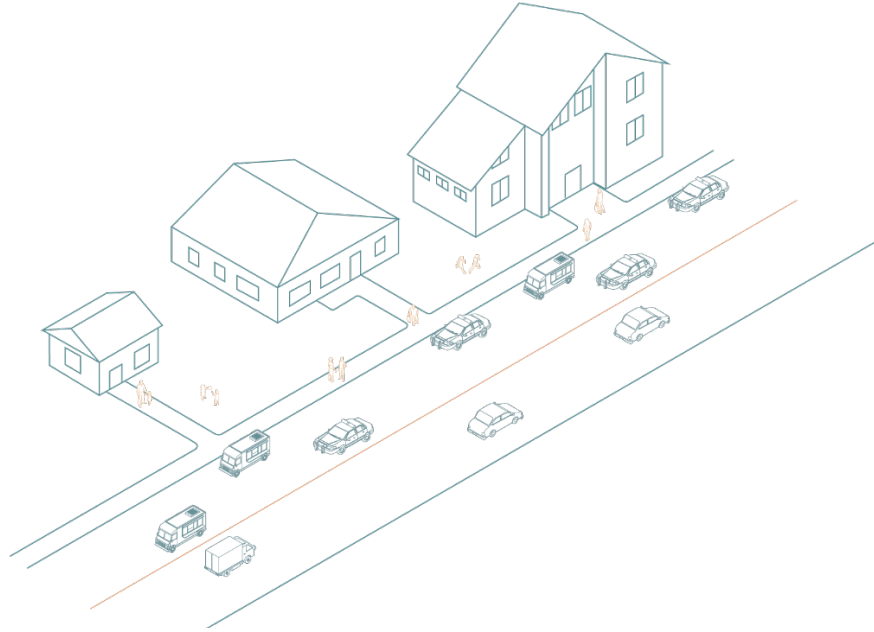


Figure 5.21 Home Delivery in the Present.

Redrawn version of original figure from Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*. Chapter 7. Detached housing with driveways and garages.

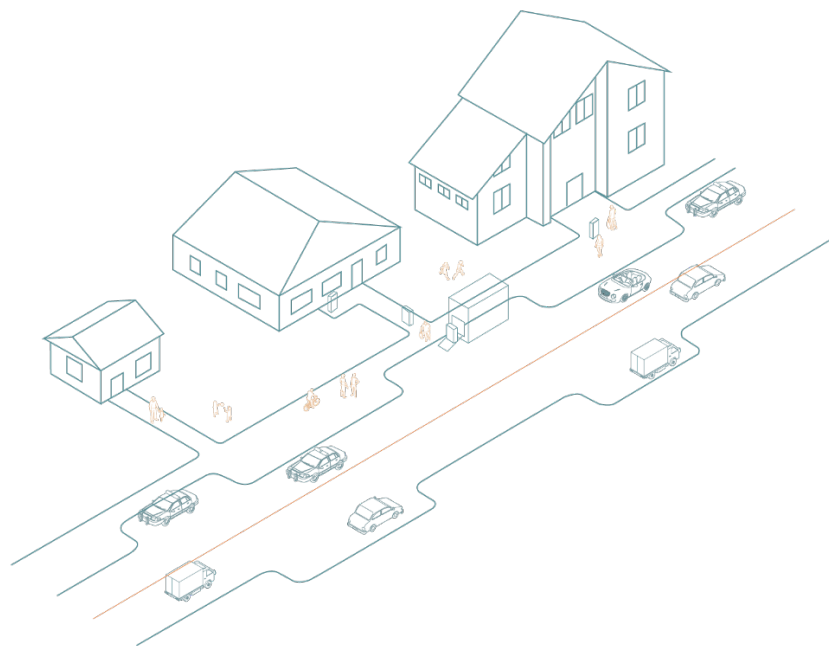


Figure 5.22 Home Delivery in the Future.

Redrawn version of original figure from Meyboom, AnnaLisa. *Driverless Urban Futures: A Speculative Atlas for Autonomous Vehicles*. Chapter 7. Renovated housing with SAV network pull-outs and reallocated space.

Figures 5.21 and 5.22 depict the future changes in home delivery methods. Typically, robots could deliver packages to the doorstep and send notifications to inform the customer. For important packages, delivery vehicles may place the item in a secure box, accessible only to the residents with the password.

However, there are also concerns about the driverless world. Some individuals worry that certain types of commercial vehicles might become as bothersome as spam. People have envisioned a scenario where streets are filled with roving robotic grocery stores, food trucks, clothing stores, and vending machines. To address this potential issue, it is crucial for the government and planners to establish regulations in advance.¹⁰⁵

5.2 Illustrative Example

Using Seattle's Belltown as a case study, this thesis demonstrates how our city would evolve into a driverless future. Firstly, the thesis will illustrate the transition from automobile-oriented roads to AV-oriented roads, following the three phases mentioned in the previous planning section. Subsequently, this part will showcase the design of a shared-use street for pedestrians.

5.2.1 *Site: Belltown*

To vividly depict the urban design concepts, this section will employ Belltown as an illustrative case study to portray the envisioned driverless future. Commencing with a concise overview of Belltown, Seattle's most densely populated neighborhood, the thesis will

¹⁰⁵ Jason Koebler, "Autonomous Vehicles Will Bring the Rise of 'Spam Cars'", vice, June 18, 2014. <https://www.vice.com/en/article/pgak49/autonomous-vehicles-will-bring-the-rise-of-spam-cars>

subsequently outline potential urban developments corresponding to distinct phases as delineated from previous research.



Figure 5. 23 The Study Area of Belltown.

Belltown, situated along the downtown Seattle waterfront, has evolved from a low-rent, semi-industrial arts district into a vibrant hub featuring trendy restaurants, boutiques, nightclubs, residential towers, as well as warehouses and art galleries.¹⁰⁶ Encompassing an area of approximately 216 acres and housing a population of 11,979 residents, Belltown serves as a crucial channel, as depicted in Figure 5.23, connecting downtown Seattle with the uptown area. Belltown experiences a continuous flow of vehicles daily and boasts a diverse range of public transportation options, such as RapidRide, Regular bus, streetcar, and more.

¹⁰⁶ Wikipedia. 2009. "Belltown, Seattle." Last modified May 22, 2023. https://en.wikipedia.org/wiki/Belltown,_Seattle.

This study utilizes the border of Belltown, showing Figure 5.23, as a research border to illustrate the gradual development of the city to enter a driverless future. This development should synchronize with the development of 3 Scenarios which were introduced before.



Figure 5. 24 The Present Road System of Belltown.

In the present, Belltown is experiencing congestion and a limit of parking spaces every day. Many of its streets are configured with a configuration of 3 or 4 driving lanes, resulting in restricted room for sidewalks. This congestion contributes to a cacophony of noise, increased pollution levels, and an excessive number of vehicles, culminating in an inhospitable and perilous pedestrian atmosphere for local residents.



Figure 5. 25 The Designed Road System of Belltown in 2040.

Figure 5.25 presents a prospective vision for the Belltown road infrastructure in the year 2040. This study operates under the assumption that autonomous driving technology and AV adoption rates will have reached a sufficient level for our city to transition into Phase 2. During this period, a substantial portion of the population will possess AVs, and our city should gradually evolve into an autonomous urban environment. Consequently, this study designates certain roads as exclusive to AVs or as hybrid roads (accessible to both AVs and HVs) by 2040. Meanwhile, a set of main roads, as introduced in section 4.25, will be designated as key entry and exit roads for AVs to access Belltown. These roads will feature fewer and narrower lanes specifically designed for AV use, thereby liberating a significant amount of space to be repurposed as public areas for pedestrians. This transformation will result in Belltown becoming a neighborhood characterized by its pedestrian-friendly and human-oriented design.



Figure 5. 26 The Designed Road System of Belltown in 2060.

As technology continues to advance and ownership of autonomous vehicles becomes widespread, phase 3, projected to be achieved by 2060, envisions Belltown's transformation into a fully autonomous urban environment. In this phase, all roads within Belltown will be designated as AV roads, resulting in a significant reduction in traffic congestion. Belltown will evolve into a secure, livable, and human-centered neighborhood. Autonomous vehicle infrastructures will replace the existing transportation systems, with vehicles seamlessly connected to the Internet. The orchestration of traffic flow throughout the city will be managed

by AI, ensuring smooth, safe, and efficient transportation. The transfer of transportation methods will be seamless and intelligent, streamlining the movement of people and goods.

Figure 5.26 provides a visual representation of various design ideas discussed earlier in the thesis, highlighting their potential locations within Belltown:

A: Represents the road design illustrated in Figure 5.1, featuring a central park for pedestrians. This design utilizes the width of Alaskan Way and a few pedestrians on sidewalk to create a recreational park. Because there is a train rail on the north side, a central recreational park will be away from the noise.

B: Represents the design concept in Figure 5.2, featuring a central rail transit system with transfer islands on both sides. This design takes into account the presence of current streetcars along this street.

C: Represents the bus lane design from Figure 5.3, which includes dedicated bus lanes in the center with transfer islands on both sides. This design is tailored to the routes of buses operating along these streets.

D: Represents the concept from Figure 5.4, featuring a narrow pedestrian area in the center with two drive lanes and spacious public areas on both sides. This design leverages the ample width of Second Avenue and its abundant public resources on both sides.

E: Illustrates the design in Figure 5.5, which features two narrow drive lanes in the middle, allowing for expansive sidewalks for public activities.

F: Represents the shared surface design depicted in Figure 5.8, where pedestrians and vehicles coexist on the road. This design aims to enhance the shared nature of Bell Street, which is already designated as a shared use surface but requires further development.

Parking structures (P) are strategically located along the main roads at the border of Belltown, as discussed in previous research (Section 4.25). These parking structures cater to the changing needs of an autonomous city and facilitate efficient vehicle storage.

As Belltown evolves into Phase 3, the culmination of these design concepts and transformations will contribute to a harmonious and vibrant urban environment that prioritizes the well-being and quality of life for its residents and visitors.

5.2.2 *Selected Example of Urban Surface*



Figure 5. 27 Bell Street in the Future.

Figure 5.27 presents an animated depiction of Bell Street within the context of a driverless future. In the present, Belltown also functions as a shared-use surface for both pedestrians and vehicles. However, due to the high speed of vehicles, street parking, and a lack of transparent openings on both sides, Belltown does not offer a pleasant experience for pedestrians.

Consequently, this design aims to showcase how a vibrant environment can be created on Bell Street.

In this vision, Bell Street undergoes a transformation to become a vibrant shared space that prioritizes pedestrian comfort and fosters community interaction. The shared surface design allocates ample room for public activities, street furniture, and greenery, enhancing the overall appeal and sense of unity within the area. Street parking are eliminated on Bell Street.

Autonomous vehicles (AVs) traversing Bell Street will adhere to significantly reduced speeds and people will feel safe and pleasant as AVs replaced human-driven vehicles on the street, ensuring harmonious coexistence with pedestrians and non-motorized transportation (NMT) participants. The inclusion of various activities and retail establishments along both sides of the street contributes to the heightened livability and vibrancy of Bell Street, fostering a thriving urban atmosphere.

Chapter 6. Conclusion & Future Work

In conclusion, autonomous vehicles present both advantages and disadvantages for cities. This research has engaged in various debates surrounding autonomous vehicles, shedding light on their potential impact. While autonomous vehicles hold the promise of new opportunities for urban planning, concerns persist that they could exacerbate existing urban challenges or introduce new ones. Additionally, questions regarding the timeline and methods of fully replacing traditional automobiles with autonomous vehicles remain uncertain. However, the inevitability of a driverless future cannot be denied. Despite the unpredictability of technological advancements and the obstacles that lie ahead, urban planners must seize and prepare for this transformative opportunity.

The primary objective of this thesis is to provide key focal points for urban planners and to offer illustrative planning and design concepts. By leveraging the findings of this research, urban planners can better navigate future city development and refine their approaches to urban planning.

The initial chapter established the scope and outline of this research, clarifying that it primarily employed qualitative research methods. The thesis relied on literature research to distill the implications of autonomous vehicles for urban planning.

The second chapter conducted a brief review of modern road development, highlighting current urban challenges. The emergence of autonomous vehicles introduces novel prospects for urban planners. Through an analysis of debates within the urban planning sphere, the thesis explained the significance of autonomous vehicles for urban planners and established the foundational rationale for this research.

The third chapter delved into the implications of autonomous vehicles on urban planning. Drawing insights from the literature review, it was evident that autonomous vehicles held the potential to profoundly reshape cities. Balancing the advantages and disadvantages, this section underscored the importance of preparing for and considering these implications in future planning endeavors.

The fourth chapter unveiled potential urban transformations that will emerge as autonomous vehicles gain widespread adoption. Alterations in urban structure, transportation systems, and mobility patterns were comprehensively explored. Urban planners could leverage these insights to formulate more suitable plans for constructing driverless cities. The thesis also outlined three phases for city development, transitioning from the present to a driverless future. Recognizing the challenges that may arise in Phase 2, this section proposed strategies to mitigate issues and expedite progression toward the more ideal Phase 3, which represents a fully realized driverless future.

The fifth chapter provided practical design ideas for urban transportation systems, equipping planners and designers with tangible concepts for building driverless cities. Using Seattle Belltown as a case study, the thesis offered guidance on how a city can evolve into a driverless urban environment.

Nevertheless, it's important to acknowledge that this thesis proposes anticipated ideas about autonomous vehicles, and there are certain limitations.

In fact, the thesis just proposes some predictable ideas on autonomous vehicles. The research on autonomous driving technology is constrained, given the primary focus on urban planning. The timeline for the implementation of autonomous vehicles remains uncertain, and

complex issues such as crash liability still require resolution by law makers and insurance entities.

Future research should delve into more detailed phase-by-phase plans for city transformation. Efforts should be directed towards guiding governmental investments in urban development. Additionally, a closer collaboration between transportation engineers, policy makers, and vehicle manufacturers is imperative to address the multifaceted challenges and opportunities that autonomous vehicles bring forth.

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