

LB/TH/44/2025
TH6031

**EVALUATING THE IMPACT OF CONNECTED AND
AUTONOMOUS VEHICLES ON AIRPORT ROADWAY
OPERATIONS**

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DECLARATION

I affirm that this thesis is entirely my original work and does not include any unacknowledged material that has been previously submitted for a degree or diploma at any other university or educational institution. To the best of my knowledge, this thesis does not contain any content that has been previously published or authored by others, except for properly cited references. I reserve the right to utilize this content, either in whole or in part, in future publications such as articles or books.

.....

Date: 05.03.2025

N.P Jayawardhana

The candidate has conducted research for their master's thesis under my guidance. I verify that the statement made by the student above is accurate and truthful.

.....

Date: 18.03.2025

Prof. H. R. Pasindu

DEDICATION

Dedicated to my beloved family, whose unwavering encouragement has been a constant source of strength throughout the significant milestones of my life. I would also like to extend my sincere gratitude to my supervisor, Professor H. R. Pasindu, for the invaluable motivation and dedicated mentorship provided throughout this process.

ACKNOWLEDGEMENT

First and foremost, I want to express my heartfelt thanks to my supervisor, Professor H. R. Pasindu, for his exceptional guidance and consistent support throughout my research on airport roadway operations. His encouragement and help with managing project deadlines and tackling obstacles have been invaluable and are deeply appreciated.

I am also grateful to Professor J. M. S. J. Bandara and Professor W. K. Mampearachchi for their thoughtful feedback and recommendations during the review stages, which have greatly improved my work.

I would like to express my gratitude to all the academic staff in the Department of Civil Engineering at the University of Moratuwa for providing a solid technical foundation throughout my undergraduate studies.

Special thanks go to Mr. Pasindu Malshan and Mr. Sajith Udayanga for their engaging discussions that aided me in exploring different solutions to my research questions. I also appreciate Pasindu and Sudara for their support with the Vissim simulations, which were crucial to the completion of my study.

ABSTRACT

The introduction of connected and autonomous vehicles (AVs) offers significant potential to improve the capacity and efficiency of modern transportation systems. Although much of the existing research has concentrated on the beneficial effects of AVs on highway traffic flow and capacity, there has been limited exploration of how AVs might influence airport curbside and internal roadway operations. Therefore, this study is designed to examine and predict the effects of AVs on the operations of airport curbside roadways. To conduct this investigation, a microsimulation method was utilized through VISSIM, incorporating the Wiedmann 74 model to simulate car-following behavior. The parameters for autonomous vehicles were calibrated to meet the Level 4 automation standards established by the Society of Automotive Engineers (SAE). A conceptual curbside network was selected for simulation, with separate lanes designated for AVs and Human-Driven Vehicles (HDVs). Six scenarios were simulated, each representing incremental increases in AV penetration rates from 10% to 50%. The study focused on evaluating improvements in traffic flow metrics, including Maximum Queue Length, Vehicle Delay, and Vehicle Travel Time. Findings from this study indicate that discernible enhancements in curbside traffic flow at airports are only observed once AV penetration levels surpass 35%. Specifically, a significant improvement in traffic flow metrics, such as Maximum Queue Length, Vehicle Delay, and Vehicle Travel Time, was noted when AV penetration levels increased from 35% to 40%. The improvement in traffic flow from AVs can be primarily attributed to their ability to mitigate the stop-and-go nature of traffic which is typically observed in HDVs. Based on these findings, this study recommends simulating traffic flow scenarios with AV penetration levels of 35%, 40%, and 50% under mixed traffic conditions, without segregating lanes for AVs and HDVs to identify the exact optimal AV penetration level for curbside operations at airports.

Keywords: Autonomous Vehicles (AVs), Airport Curbside Roadway Operation, Vehicle Penetration, Microsimulation

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LIST OF ABBREVIATIONS

Abbreviation	Description
AVs	Autonomous Vehicles
HDVs	Human Driven Vehicles
SAE	Society of Automotive Engineers
TNCs	Transportation Network Companies
V2V	Vehicle-to-vehicle
SAVs	Shared Automated Vehicles
VTT	Vehicle Travel Time

CHAPTER 1

BACKGROUND

1.1 Introduction

The advent of automated vehicles (AVs) has the potential to usher in a new era for ground transportation. Research indicates that AVs could become prevalent on roads within the next 15 years.

In terms of mobility, AVs are expected to revolutionize our daily lives. With the ability to travel without driving, individuals will be freed from the stresses associated with operating a vehicle and will have the opportunity to engage in other activities during their journey.

Transport planners and policymakers are optimistic about the ability of AVs to address various traffic-related issues, such as congestion. Traditionally, increasing road capacity has been the primary approach to alleviate traffic jams.

Airports, which serve as critical intermodal nodes linking ground and air transport, have already faced challenges from new ground transportation technologies and business models, leading to changes in how passengers access airports. For instance, the introduction of transportation network companies (TNCs) led to a shift in some passengers' preferences from self-driving, family drop-offs, or other commercial options to ride sourcing services. Airports initially responded by banning TNCs but later adapted by developing pricing schemes for airport curbside use. The rise of AVs is likely to introduce further challenges to airport ground access as these technologies become more widely adopted.

AVs possess superior accuracy and sensing capabilities compared to human drivers, requiring smaller gaps or shorter headways between vehicles due to their enhanced awareness of the driving environment and reduced reaction times. Additionally, vehicle-to-vehicle (V2V) communication has the potential to form vehicle platoons, which may improve traffic flow and increase road capacity.

This study seeks to investigate and forecast the effects of autonomous vehicles (AVs) on airport roadway operations. It specifically examines how varying levels of AV penetration and the introduction of distinct lanes for AVs and human-driven vehicles (HDVs) may influence curbside operation.

1.2 Objective of the research

The advent of autonomous vehicles (AVs) has sparked significant interest and speculation regarding their potential impact on various aspects of transportation infrastructure. While much attention has been focused on their implications for urban roadways, there remains a notable knowledge gap concerning the influx of AVs and their effects on airport roadway operations.

The transition to AVs represents a paradigm shift in ground transportation, with profound implications for airport access and curbside operations. However, despite growing interest in AV technology, there is a lack of comprehensive research and analysis regarding its specific impact on airport roadways. Existing studies often focus on urban settings, overlooking the unique dynamics of airport environments and the complexities of managing ground transportation systems within these contexts.

One of the key challenges posed by the influx of AVs to airport roadways is the need to accommodate diverse modes of transportation while ensuring efficiency and safety. Unlike traditional ground transportation options, such as taxis and private vehicles, AVs introduce new variables and considerations that must be addressed in the design and management of airport curbside operations. This includes factors such as AV behavior in congested environments, integration with existing transportation infrastructure, and passenger preferences for AV usage.

Furthermore, the deployment of AVs may exacerbate existing issues related to congestion and traffic flow at airports. While AV technology holds the promise of improving efficiency and reducing travel times, its widespread adoption could also lead to increased vehicle volumes and changes in passenger behavior. Understanding how these factors interact, and impact airport roadway operations is essential for effective planning and management.

Despite these challenges, the influx of AVs also presents opportunities for innovation and optimization in airport transportation systems. By leveraging AV technology, airports can potentially streamline passenger flow, enhance accessibility, and reduce environmental impacts. For example, AVs equipped with advanced navigation systems and communication capabilities could enable dynamic routing and coordination, minimizing congestion and improving overall system performance.

Hence, the influx of AVs to airport roadway operations requires a multifaceted approach that integrates research, data collection, and stakeholder collaboration. This includes conducting empirical studies to assess the impact of AVs on airport traffic patterns, modeling future scenarios to anticipate potential challenges and opportunities, and engaging with industry stakeholders to develop strategies for effective integration.

As discussed, there is a lack of investigations on how AVs performs on airport roadways. This study has investigated specifically on the curbside operation at an airport and how it reacts to influx of autonomous vehicles. The objective of this research is to find the optimum level of AVs penetration as it increases the performance of curbside network.

1.3 Methodology

The research embraced a microsimulation methodology, driven by the paramount objective of evaluating the influence of Autonomous Vehicles (AVs) based on their behavioral dynamics. It is notable that currently, AVs remain largely absent from road networks, with only a limited number of test vehicles in operation. A comprehensive literature review was conducted to synthesize pertinent findings from related research endeavors.

To simulate curbside operation dynamics, the study employed PTV VISSIM simulation software. A conceptual framework for the curbside network was devised to facilitate the investigation. The research delved into assessing the impact on curbside

operations by varying the penetration of AVs within traffic flow, with the overarching aim of identifying the optimal penetration level.

1.4 Arrangement of the report

Chapter 1 provides an overview of the study, detailing the background, objectives, and methodology. It introduces the concept of autonomous vehicles (AVs), identifies knowledge gaps, and outlines the study's aims.

Chapter 2 conducts a comprehensive review of existing literature, encompassing discussions on AVs, airport roadways, and microsimulation models.

Chapter 3 delves into the microsimulation model, exploring driving behaviors, curbside arrangements, parking lot configurations, and vehicle composition.

Chapter 4 presents a detailed analysis of the study's findings, focusing on metrics such as Maximum Queue Length, Vehicle Delay, and Vehicle Travel Time, while varying the penetration level of AVs.

Chapter 5 provides conclusions drawn from the research findings and identifies areas for future exploration and development to deepen understanding in the field.

CHAPTER 2

REVIEW OF PREVIUOS LITREATURE

2.1 Influx of Autonomous Vehicles (AVs)

The majority of prior research endeavors have primarily focused on delineating the effects of Autonomous Vehicles (AVs) on highways and urban thoroughfares, with scant attention directed towards their influence on airport operations. Notably, prognostications from Boston Consulting Group (2014) suggest an anticipated introduction of AVs into the consumer automotive market by 2025, with a projected market share of 10% by 2035. Meanwhile, estimates provided by Litman (2015) anticipate a notable proliferation of AVs, envisaging that they will comprise between 80-100% of vehicular traffic on roads by the year 2045. Moreover, projections offered by Bansal and Kockelman (2017) project a substantial market penetration of AVs, spanning from 24% to 87%, underscoring the inevitability of AVs becoming ubiquitous on road networks within the next two decades.

In examining the threshold at which the transformative impact of AVs becomes discernible, empirical findings from Vander werf et al. (2002) caution that tangible improvements in traffic conditions may not manifest until AV penetration rates surpass 40%. Similarly, Talebpour et al. (2017), through simulation modeling on a four-lane highway, substantiate that discernible enhancements in traffic flow are only realized with AV penetration rates exceeding 30%. Moreover, Arem and Van Driel (2017) posit that the salutary effects of AV integration become perceptible once penetration rates exceed the 40% threshold.

Collectively, these findings underscore the necessity for AV penetration rates to surpass the 40% mark in order to engender discernible improvements in traffic flow dynamics.

2.2 Impact of Autonomous Vehicles (AVs) on normal traffic flow

Autonomous vehicles (AVs) hold the promise of improving traffic flow and easing the burden of growing traffic volumes on urban roads. According to research by Ji Eun

Park, Wanhee Byun, Youngchsn Kim, Hyeonjun Ahn, and Doh Kyoum Shin (2021), AVs can enhance traffic flow by reducing travel times and delays while boosting vehicle speeds. These benefits become increasingly significant with higher AV adoption rates. For example, at a 100% penetration rate, average travel time savings could reach 17%, delays could be reduced by 31%, and vehicle speeds could increase by 21%. Their study, conducted at the link level, also found that road segments with three or more lanes saw more pronounced improvements in traffic flow compared to those with fewer lanes.

The research also highlights the potential of AVs to alleviate worsening traffic conditions. However, a potential issue arises if the introduction of AVs leads to a higher overall car usage, which could complicate traffic management. Nevertheless, in a scenario where all vehicles are autonomous, the existing road infrastructure could handle 40% more traffic without needing additional construction or worsening congestion.

Despite substantial interest and investment in AV technologies, their exact impact on future transportation systems is still uncertain. Most existing studies have concentrated on AV effects on highways, overlooking their use in urban environments, where research on urban roadways is limited.

Park et al. (2021) emphasize that even a modest introduction of AVs can improve traffic flow on urban streets. Given that AVs have the potential to increase road network capacity by 40%, it is essential for transport planners and policymakers to consider AVs in future transportation system designs over the next 15 to 25 years. As trends like car-sharing and shared automated vehicles (SAVs) alter transportation patterns, planners will need to address issues related to car usage and road capacity. It is possible that future car demand might surpass the capacity of current road networks, making it necessary to either redesign roads or utilize spare capacity provided by AVs more effectively.

Safety is a paramount concern in the integration of AVs into urban environments. Research by (Anderson, et al., 2014) and ((NHSTA), 2020) suggests that AVs have the potential to mitigate human error-related crashes, which account for the majority

of traffic accidents. However, uncertainties remain regarding the safety performance of AVs, particularly in complex urban scenarios involving interactions with pedestrians, cyclists, and traditional vehicles (Chen, Li, & Li, 2019). Additionally, ethical dilemmas regarding AV decision-making in crash scenarios pose challenges for policymakers and engineers (Lin, 2016).

Effective governance frameworks are essential for managing the introduction of AVs into urban environments. Research by (Levinson, D & Krizerk, 2015) highlights the need for flexible regulations that balance innovation with safety and equity considerations. Moreover, policy interventions may be required to address concerns related to job displacement, privacy, cybersecurity, and the equitable distribution of AV benefits (Eagnant & Kockelman, 2015)

The integration of AVs necessitates adaptations to urban infrastructure and planning strategies. Studies by Sivak and Schoettle (2015) and Litman (2020) emphasize the importance of redesigning roadways, intersections, and parking facilities to accommodate AVs effectively. Moreover, AV deployment may influence land use patterns and urban sprawl dynamics, with implications for accessibility and environmental sustainability (Clewlow & Mishra, 2017).

2.3 Levels of Autonomous vehicles

As per (Engineering, 2021), the categorization of autonomous vehicles encompasses six distinct levels:

- **Level 0:** This stage represents a scenario with no automation, where the driver is entirely responsible for managing all aspects of driving. This was the standard for vehicles up until roughly the 1970s.
- **Level 1:** At this level, vehicles offer limited driver assistance, concentrating on either braking/throttle or steering functions. Nonetheless, the driver remains responsible for supervising and controlling the vehicle. Examples of Level 1 features include cruise control and Anti-lock Braking Systems (ABS).

- **Level 2:** At this stage, partial automation is introduced, allowing the system to manage some driving functions, such as steering, acceleration, and braking. Nevertheless, the driver must continuously monitor the environment and be ready to take control if needed. Systems like Tesla’s Autopilot (since 2014) and General Motor’s Super Cruise (since 2017) exemplify Level 2 automation.
- **Level 3:** This level features conditional automation, where the vehicle is capable of handling driving tasks and observing its environment under certain conditions or within its defined Operational Design Domain (ODD). The driver must be prepared to regain control within a designated timeframe if the system prompts or if the vehicle encounters conditions outside its ODD.
- **Level 4:** At this stage, high automation is achieved, with the system handling all driving responsibilities within its ODD, which may be confined to certain areas with appropriate infrastructure and specific weather conditions. As of 2018, Level 4 automation is mostly seen in research vehicles, such as Waymo’s self-driving minivan, which is moving towards ride-sharing applications.
- **Level 5:** This level represents full automation, where the vehicle can carry out all driving tasks in any environment and under all conditions without needing any input from a human driver.

The focus of this study pertains to autonomous vehicles operating at Level 4 of automation. As delineated by (Engineering, 2021), Level 4 denotes a stage characterized by a high degree of automation, wherein human intervention is seldom necessitated under most operational circumstances.

2.4 Curbside roadway operation

According to Leighfisher, Dowling Associates, Inc., JD Franz Research, Inc., and Wiltec (2010), airport roadways are divided into five categories:

1. Access Roadways
2. Curbside Roadways

3. Circulation Roadways

4. Service Roads

5. Airfield Roads

Given the critical role of Curbside Roadways within airport infrastructure, this study focuses specifically on the effects of Autonomous Vehicles (AVs) on the operation of these curbside roadways.

Leighfisher et al. (2010) describe curbside operations as involving one-way roadways located directly beside terminal buildings, where vehicles stop to enable passengers and their luggage to embark and disembark.

Leighfisher et al. (2010) highlight that when evaluating the capacities and service levels of airport curbside roadways, it is essential to consider both the efficiency of the curbside lanes and the through lanes together. This is due to the fact that the total capacity and service quality of the curbside roadway system are governed by the component with the smallest capacity or the poorest service level.

In addition to curbside utilization, which is the main performance metric, Leighfisher and colleagues (2010) recommend five other performance measures:

- **Number of vehicles parked in the second and third lanes:** This measure assesses the extent of roadway congestion resulting from vehicles occupying through lanes for parking purposes.
- **Number of through lanes blocked by parked or parking vehicles:** This metric quantifies the degree of roadway congestion attributable to parked or parking vehicles obstructing through lanes.
- **Queue Length:** Queue length measures the number of vehicles waiting to access a curbside roadway or parking area. It is typically evaluated based on the length of the vehicle line extending from the parking area or congestion point.

- **Queuing Duration:** This metric, expressed in minutes, signifies the duration for which congestion persists along the curbside roadway, thereby providing insights into temporal traffic dynamics.
- **Average Vehicle Delay:** Average Vehicle Delay is composed of two primary elements: through traffic delay and curbside loading/unloading delay.

Through Traffic Delay is the duration a vehicle takes to traverse the entire curbside area. This is calculated by subtracting the travel time under free-flow conditions from the actual observed travel time.

Curbside Loading/Unloading Delay refers to the time vehicles spend in curbside parking spaces for loading or unloading passengers. This delay is determined by subtracting the average dwell time indicative of the minimum time required for passenger pick-up or drop-off during periods of low congestion from the total observed average time.

Together, these performance measures provide a detailed understanding of the operational efficiency and congestion issues at airport curbside roadways.

2.5 Microsimulation model

(Leighfisher, Dowling Associates, Inc., JD Franz Research, Inc., & Wiltec, 2010) assert that the utilization of microsimulation models facilitates a comprehensive analysis of curbside roadways, enabling the consideration of parameters such as the number of vehicles parked in secondary and tertiary lanes, queue length, duration of queuing, and average vehicle speeds or delays. The intricate nature of curbside roadway dynamics, characterized by relatively limited distances and challenges in estimating queue lengths through conventional means, underscores the indispensability of microsimulation modeling for accurate assessments.

In accordance with (Ahmed, Huang, & P.lu, 2021), microsimulation modelling serves as a pivotal methodology for evaluating the impact of Autonomous Vehicles (AVs), with a particular emphasis on traffic performance. Consequently, this study adopts a microsimulation approach, recognizing its efficacy in assessing AV impact based on

their behavioral dynamics. It is pertinent to note that while AVs are not yet commonplace on curbside roadways, with only a few test vehicles in operation, their potential influence warrants rigorous investigation.

(ATKINS, 2016) delineates default parameter values for AVs within VISSIM at SAE level 3 of automation. However, this study aligns AVs with SAE level 4 and derives parameter values from previous studies, including those by (Ji Eun Park et al., 2021), (ATKINS, 2016), and (Kang, Song, Hwang, & I. J. Im, 2019).

In a study conducted by (Hwapyeong Yu, Sehyun Tak, Minju Park, & Hwasoo Yeo, 2019), the impact of autonomous vehicle-only lanes in mixed traffic conditions was investigated. Findings revealed that the safety of mixed traffic was contingent upon the market penetration rate of autonomous vehicles (AVs) shows that AV-only lanes offer notable benefits in terms of efficiency and safety, especially in merging and diverging sections of highways, even when AV adoption levels were below 40%. Notwithstanding the safety benefits, AV-only lanes may engender adverse effects on traffic efficiency, potentially exacerbating congestion due to a reduction in lanes for Human-Driven Vehicles (HDVs). Consequently, the microscopic model employed in this study will delineate separate curbside lanes for AVs and HDVs to comprehensively evaluate their operational dynamics.

CHAPTER 3

MICROSIMULATION MODEL

The study employed a microsimulation methodology, as its primary objective is to evaluate the impact of Autonomous Vehicles (AVs) based on varying penetration levels. Additionally, a conceptual road network was utilized to discern the effects of AVs on airport curbside operations.

3.1 Driving Behaviors

As outlined in the Literature Review section, microsimulation traffic modeling is the predominant approach for studying Autonomous Vehicles (AVs), especially regarding traffic performance. Within this framework, VISSIM offers two main car-following models: Wiedemann 74 and Wiedemann 99. According to the VISSIM user manual, the Wiedemann 74 model is particularly suited for urban environments, while the Wiedemann 99 model is designed for motorway traffic simulations. Given that our research focuses on evaluating the impact of AVs on curbside operations, we chose to implement the Wiedemann 74 model.

VISSIM allows users to modify parameters related to car-following behaviors, lane changes, and driver characteristics. Accordingly, several parameters were adjusted to accurately represent the behavior of AVs in our simulations. For this study, AVs were categorized as Level 4 according to the Society of Automotive Engineers (SAE) taxonomy, with parameter values based on relevant previous research.

Table 3.1

Parameters for modeling AVs

Parameters		AVs
Car Following (Wiedeman 74)	Standstill distance(m)	0.5
	Headway time(s)	0.5
Lane change	Min. headway (m)	0.2
	Safety distance reduction factor (%)	30

	Cooperative lane change difference(km/h)	Min. speed	10
		Max. collision time(s)	10
Driver characteristics	Look ahead distance(m)	Min.	0
		Max.	500
	Look back distance(m)	Min.	0
		Max.	500
	Desired speed(km/h)	Lower bound	50
		Upper bound	50
	Driver Errors (%)		0
Automated driving/Platooning possible	Max. number of vehicles		7
	Max. desired speed(km/h)		50
	Max. distance for catching up to a platoon(m)		30
	Gap time(s)		0.2
	Minimum clearance(m)		2

Table 3.1 displays the parameters used in this study. The car-following and lane change parameters for Autonomous Vehicles (AVs) were adjusted to reflect their more assertive and responsive driving behaviors compared to human drivers. Furthermore, AVs were allowed to perform cooperative lane changes.

In terms of driver characteristics, it was assumed that AVs have superior communication capabilities, allowing them to interact seamlessly with other AVs and access comprehensive traffic information. For AVs, the target speed was set uniformly at 50 km/h, while Human-Driven Vehicles (HDVs) were assigned a speed range of 48 to 58 km/h. It was also assumed that HDVs have a 10% error rate, which could lead to avoidable road conflicts. The model framework assigned platooning functionalities exclusively to AVs, with HDVs using the default parameter settings provided by VISSIM.

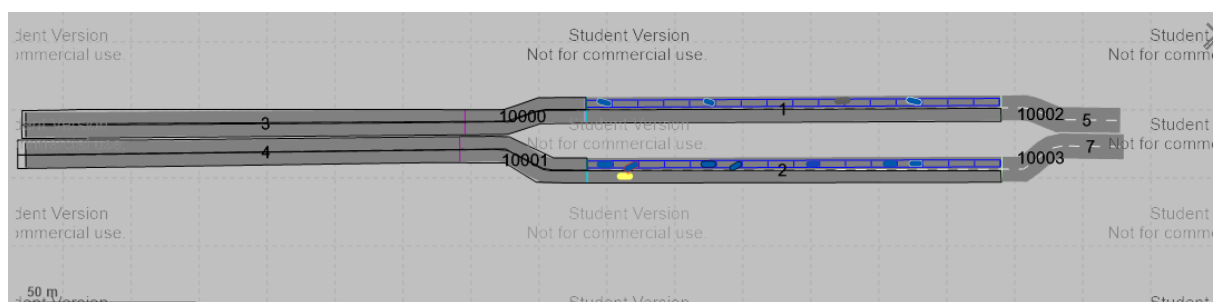
3.2 Curbside arrangement

As detailed in the literature review, this model features separate segments for Autonomous Vehicles (AVs) and Human-Driven Vehicles (HDVs).

The primary reason for providing a dedicated AV lane in this study is to enhance safety in environments where AVs interact with human-driven vehicles, all of which follow different patterns of behavior. In mixed traffic conditions, the predictability and decision-making of human drivers can present challenges for AVs, which rely on precise data to navigate safely. By isolating AVs in a designated lane, potential conflicts with human-driven vehicles are minimized, reducing the risk of accidents due to unpredictable human actions, such as sudden lane changes or erratic driving. Additionally, dedicated lanes allow AVs to operate within their optimal parameters, ensuring more accurate responses to traffic signals, road markings, and other infrastructural elements. This separation not only ensures the safety of AVs but also promotes the safety of passengers, airport staff, and other road users. As AV technology continues to evolve, a dedicated lane provides a controlled environment that can help foster safer integration into broader traffic networks while minimizing the risks associated with mixed traffic.

Figure 3.1

Curbside Arrangement- Layout



3.3 Link behaviors

As illustrated in Figure 3.2, Links 1, 3, and 5 are designated exclusively for Autonomous Vehicles (AVs), guaranteeing that these routes are reserved for vehicles equipped with advanced automation technology. In contrast, Figure 3.3 illustrates that Links 2, 4, and 7 are designated exclusively for Human-Driven Vehicles (HDVs),

indicating that these routes are intended for vehicles controlled manually by drivers. This segregation aims to optimize traffic flow and safety by clearly differentiating between the paths used by autonomous and human-driven vehicles.

Figure 3.2

Link Behavior Types - AVs link

Number: 6	No	Name	DrivBehavDef
	1	1 Urban (motorized)	1: Urban (motorized)
	2	2 Right-side rule (motorized)	2: Right-side rule (motorized)
	3	3 Freeway (free lane selection)	3: Freeway (free lane selection)
	4	4 Footpath (no interaction)	4: Footpath (no interaction)
	5	5 Cycle-Track (free overtaking)	5: Cycle-Track (free overtaking)
	6	6 AV Link	104: AV level 4

Figure 3.3

Link Behavior Types - HDVs link

Number: 6	No	Name	DrivBehavDef
	1	1 Urban (motorized)	1: Urban (motorized)
	2	2 Right-side rule (motorized)	2: Right-side rule (motorized)
	3	3 Freeway (free lane selection)	3: Freeway (free lane selection)
	4	4 Footpath (no interaction)	4: Footpath (no interaction)
	5	5 Cycle-Track (free overtaking)	5: Cycle-Track (free overtaking)
	6	6 AV Link	104: AV level 4

Each link comprises two lanes, with each lane measuring 3.5 meters in width. Specifically, Links 2, 4, and 7 have been allocated for Urban (motorized) traffic, as shown in Figure 3.4. This designation indicates that these links are intended to accommodate vehicles operating within an urban environment.

Figure 3.4

Link attributes - HDVs link

Num. of lanes:	2	Link behavior type:	1: Urban (motorized)																																							
Link length:	141.832 m	Display type:	1: Road gray																																							
		Level:	1: Base																																							
<table border="1"> <thead> <tr> <th>Lanes</th> <th>Meso</th> <th>Pedestrian Area</th> <th>Display</th> <th>Dyn. Assignment</th> <th>Others</th> </tr> </thead> <tbody> <tr> <td>Number: 2</td> <td>Index</td> <td>Width</td> <td>LinkBehav...</td> <td>BlockedVe...</td> <td>DisplayType</td> <td>MarkingTy...</td> <td>NoLnChLA...</td> <td>NoLnChR...</td> <td>NoLnChLV...</td> <td>NoLnChRV...</td> </tr> <tr> <td></td> <td>1</td> <td>3.50</td> <td></td> <td></td> <td></td> <td>1: Default</td> <td><input type="checkbox"/></td> <td><input type="checkbox"/></td> <td></td> <td></td> </tr> <tr> <td></td> <td>2</td> <td>3.50</td> <td></td> <td></td> <td></td> <td>1: Default</td> <td><input type="checkbox"/></td> <td><input type="checkbox"/></td> <td></td> <td></td> </tr> </tbody> </table>				Lanes	Meso	Pedestrian Area	Display	Dyn. Assignment	Others	Number: 2	Index	Width	LinkBehav...	BlockedVe...	DisplayType	MarkingTy...	NoLnChLA...	NoLnChR...	NoLnChLV...	NoLnChRV...		1	3.50				1: Default	<input type="checkbox"/>	<input type="checkbox"/>				2	3.50				1: Default	<input type="checkbox"/>	<input type="checkbox"/>		
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	1	3.50				1: Default	<input type="checkbox"/>	<input type="checkbox"/>																																		
	2	3.50				1: Default	<input type="checkbox"/>	<input type="checkbox"/>																																		

Links 1, 3, and 5 have been designated as Autonomous Vehicle (AV) links, in accordance with their assigned link behavior type, as shown in Figure 3.5. This allocation indicates that these links are reserved exclusively for autonomous vehicles,

ensuring that the infrastructure is specifically designed to meet the needs and operational requirements of AVs.

Figure 3.5

Link attributes - AVs link

Num. of lanes:	2	Link behavior type:	6: AV Link							
Link length:	141.562 m	Display type:	1: Road gray							
		Level:	1: Base							
<table border="1"> <tr> <td>Lanes</td> <td>Meso</td> <td>Pedestrian Area</td> <td>Display</td> <td>Dyn. Assignment</td> <td>Others</td> </tr> </table>				Lanes	Meso	Pedestrian Area	Display	Dyn. Assignment	Others	
Lanes	Meso	Pedestrian Area	Display	Dyn. Assignment	Others					
Number: 2	Index	Width	LinkBehav...	BlockedVe...	DisplayType	MarkingTy...	NoLnChLA...	NoLnChR...	NoLnChLV...	NoLnChRV...
1	1	3.50				1: Default	<input type="checkbox"/>	<input checked="" type="checkbox"/>		
2	2	3.50				1: Default	<input checked="" type="checkbox"/>	<input type="checkbox"/>		

3.4 Curbside Parking lots

Number of parking slots (Curbside Length) was changed with the vehicle volume assuming dwell time and average vehicle stall length are constant for all scenarios.

$$R_a = V * D_i / 60 * L$$

where,

R_a = the average length of curbside needed to accommodate vehicles stopping in a curbside area

V = the hourly volume of vehicles stopping in a curbside area

D_i = the average dwell time of each vehicle (in minutes)

L = the average length of each vehicle stall

Table 3.2 shows the numbers of parking slots were provided for AVs and HDVs in each scenario.

Table 3.2

Number of parking lots for each scenario

AV penetration Level	Total Volume	Vehicle Volume		Number of Parking slots (Curbside Length)	
		AVs	HDVs	Avs Link	HDVs Link
10%	400	40	360	3	21
20%	400	80	320	5	19

30%	400	120	280	7	16
35%	400	140	260	8	15
40%	400	160	240	9	14
50%	400	200	200	12	12

3.5 Curbside Parking Lots Configuration

3.5.1 Dynamic Assignment

The composition was classified as 'Car AV,' and for the purpose of Autonomous Vehicle (AV) parking lots, a default desired speed of 50 km/h was established. This speed allocation is specifically set to ensure that vehicles operating within these designated parking areas adhere to a standard rate of travel, which is deemed appropriate for maintaining safety and efficiency in AV parking facilities.

Figure 3.6

Parking Lot Configuration – Dynamic Assignment (AV parking lots)

The screenshot shows the 'Parking Lot' configuration window with the following settings:

- No.: 1
- Link: 1
- Length: 53.200 m
- At: 13.920 m
- Show label:
- Evaluation groups: 1, 2
- Type: Zone Connector, Abstract parking lot, Real parking space
- Dyn. Assignment: Rel. flow: 1.0, Capacity: 7 Veh, Initial occupancy: 0 Veh
- Parking Spaces: Zone: [dropdown], Destination group: 0, Routing decision distance: 50.00 m
- Sel. parameters: Composition: 3: Car AV, Default Desired Speed: 50: 50 km/h

The composition was designated as 'Car only,' and for Human-Driven Vehicle (HDV) parking lots, a default desired speed of 30 km/h was established. This speed limit is set to ensure that vehicles operating within these parking areas travel at a controlled pace, which helps in managing safety and improving overall efficiency in HDV parking facilities.

Figure 3.7

Parking Lot Configuration – Dynamic Assignment (HDV parking lots)

The screenshot shows the 'Parking Lot' configuration window. The 'No.' field is set to 2, 'Link' to 2, 'Length' to 121.600 m, and 'At' to 13.929 m. The 'Type' is 'Real parking space'. 'Evaluation groups' 1 and 2 are listed, with group 2 selected. The 'Dyn. Assignment' tab is active, showing 'Rel. flow' as 1.0, 'Capacity' as 16 Veh, 'Initial occupancy' as 0 Veh, and 'Default Desired Speed' as 30: 30 km/h. Other fields include 'Zone', 'Destination group', 'Routing decision distance', and 'Composition'.

3.5.2 Parking spaces

The length of a parking lot is established at 7.6 meters. The block time duration denotes the period during which arriving vehicles remain obstructed, essentially representing the maneuvering time required for parking. This duration was uniformly set at 0.5 seconds for both scenarios.

Additionally, the parking direction dictates the way of vehicles enter and exit the space. In alignment with parallel parking scenarios, the assignment for both AV and HDV parking lots was configured as Forward > Forward.

Figure 3.8

Parking Lot Configuration – Parking Spaces

The screenshot shows the 'Parking Lot' configuration window. The 'No.' field is set to 1, 'Link' to 1, 'Length' to 53.200 m, and 'At' to 13.920 m. The 'Type' is 'Real parking space'. 'Evaluation groups' 1 and 2 are listed, with group 1 selected. The 'Dyn. Assignment' tab is active, showing 'Link - lane' as 1 - 2, 'Length of each space' as 7.600 m, 'Blocking time distribution' as 1: 0.5 s, 'Parking direction' as Forward > forward, 'Minimum gap time major flow' as 5.0 s, 'Speed (forward driving)' as 5.00 km/h, 'Speed (reversing)' as 5.00 km/h, and 'Direction change time distribution' as 3: 5 s ±.

3.5.3 Sel. Parameters

The maximum parking time has been designated as 200 seconds for both scenarios. Open hours have been established at 99999 seconds to ensure that the parking lots remain accessible throughout the entire simulation duration. Attraction values have been allocated under the assumption that vehicles are inclined to gravitate towards the nearest available parking lot.

Figure 3.9

Parking Lot Configuration – Sel. parameters

The screenshot shows a software dialog box titled "Parking Lot" with a "Sel. parameters" tab selected. The dialog contains several input fields and checkboxes. The "No." field is set to 1, "Link" to 1, "Length" to 53.200 m, and "At" to 13.920 m. The "Type" section has three radio buttons: "Zone Connector", "Abstract parking lot", and "Real parking space", with "Real parking space" selected. The "Show label" checkbox is checked. The "Evaluation groups" section has two checkboxes, "1" and "2", with "1" selected. The "Open hours" section has "From" set to 0 s and "until" set to 99999 s, with "Maximum parking time" set to 200 s. The "Attraction" section has "First" set to 7.0 and "Last" set to 1.0. The "Parking fee" section has "flat" set to 0.0 and "per hour" set to 0.0. The dialog has "OK" and "Cancel" buttons at the bottom right.

3.6 Parking route decisions

All vehicle types are permitted to park, and the parking rate has been fixed at 100%, presuming that all vehicles entering the network are either for drop-off or pick-up purposes. The parking duration has been defined as a normal time duration, with an upper bound set at 200 seconds. The mean duration is 150 seconds, with a standard deviation of 5 seconds.

Regarding the full occupancy behavior, it specifies the course of action when all parking lots are occupied. Given the focus of this model on curbside operations, it is assumed that all vehicles will wait until a parking lot becomes available.

Figure 3.10

Parking Routing Decisions

Parking Routing Decisions / Parking routes											
Count	No	Name	Link	Pos	AllVehTypes	VehClasses	ParkRate(0-MAX)	ParkDur(0-MAX)	GenBy	FullOccupBeha	Filter
1	2		4	127.766	<input checked="" type="checkbox"/>		100.00 %	106	User	Wait	
2	3		3	129.327	<input checked="" type="checkbox"/>		100.00 %	106	User	Wait	

Figure 3.11

Time Distributions

Time Distributions / Data Points							
Count	N	Name	Type	LowerBound	UpperBound	StdDev	Mean
1	1	0.5 s	Normal	0.00	0.50	0.00	0.50
2	2	0.9 s	Normal	0.00	0.90	0.00	0.90
3	3	5 s ±	Normal	0.00	15.00	1.00	5.00
4	20	20 s ±	Normal	0.00	40.00	2.00	20.00
5	30	30 s ±	Normal	0.00	130.00	10.00	30.00
6	101	2.0 s	Normal	0.00	2.00	0.00	2.00
7	102	1.5 s	Normal	0.00	1.50	0.00	1.50
8	103	0.6 s	Normal	0.00	0.60	0.00	0.60
9	104		Empirical	150.00	200.00	0.00	20.00
10	105		Normal	0.00	280.00	10.00	180.00
11	106		Normal	0.00	200.00	5.00	150.00

3.7 Vehicle composition

Two vehicle compositions have been delineated for the purpose of incorporating vehicles into the simulation:

Car AV: This composition exclusively consists of cars, with the desired speed set at 50 km/h.

Figure 3.12

Vehicle Compositions - AVs

Number:	No	Name
1	1	Default
2	2	Car only
3	3	Car AV

Number:	VehType	DesSpeedDistr	RelFlow
1	100: Car AV	50: 50 km/h	1.000

Car only: Similarly comprised solely of cars of the same size as those in the Car AV composition, albeit with a desired speed set at 30 km/h.

Figure 3.13

Vehicle Compositions- HDVs

Number:	No	Name
1	1	Default
2	2	Car only
3	3	Car AV

Number:	VehType	DesSpeedDistr	RelFlow
1	3: Car Only	30: 30 km/h	1.000

3.8 Vehicle Inputs

The total number of vehicles remained constant at 400 vehicles per hour, with variations applied according to the respective scenarios as outlined in the Table 3.3.

Table 3.3

Vehicle inputs for each scenario

Scenario	Total Volume	AV penetration Level	AV Volume	HDV Volume
1	400	10%	40	360
2	400	20%	80	320
3	400	30%	120	280
4	400	35%	140	260
5	400	40%	160	240
6	400	50%	200	200

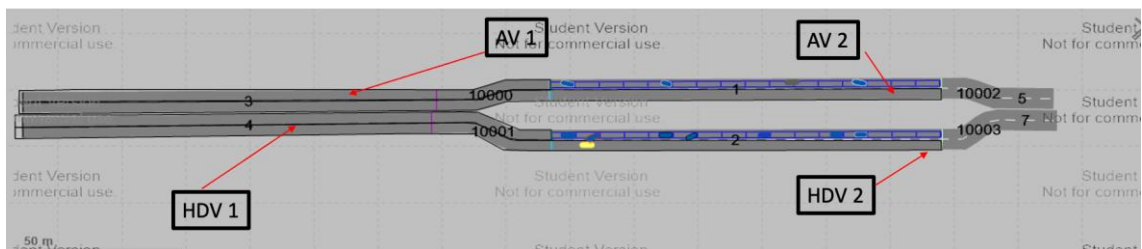
3.9 Data collection

Four nodes have been strategically positioned along each link to facilitate the computation of Vehicle Delay and Queue Length.

- Movement 1(HDV1) – HDV through lane
- Movement 2 (HDV2) - HDV 2nd lane
- Movement 3 (AV1) - AV through lane
- Movement 4 (AV2) - AV 2nd lane

Figure 3.14

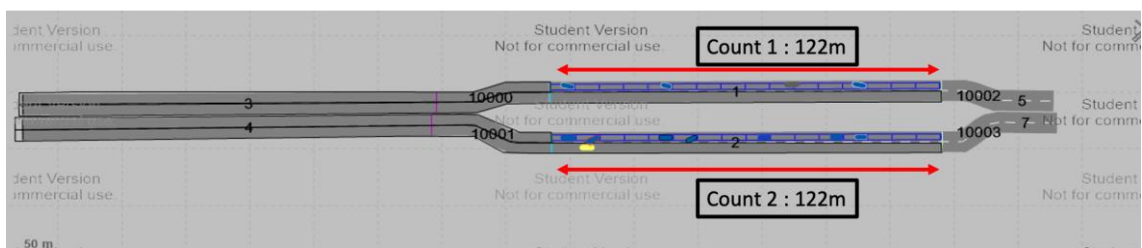
Location of Nodes



The four nodes have been positioned to gather data independently for both the through and second lanes. Additionally, two Vehicle Travel Time counters have been installed to compute Vehicle Travel Time for both AV and HDV sections, with each section spanning a length of 122 meters. Counter 1 is situated within the AV section, while counter 2 is positioned within the HDV section.

Figure 3.15

Location of Vehicle Travel Time counters



CHAPTER 4

RESULTS AND DISCUSSION

Three performance measures were employed to assess the effectiveness of curbside operations across the six microsimulation models.

1. Maximum Queue Length
2. Vehicle Delay
3. Vehicle Travel Time

All models maintained identical vehicle flows, with variations only introduced through changes in autonomous vehicle (AV) penetration levels.

Detailed results for each simulation can be found in Appendices A through F. A summary of these performance measures is presented in Table 4.1.

Table 4.1

Summary of Performance

Performance Measure	AV Penetration					
	10%	20%	30%	35%	40%	50%
Max Queue Length (m)	160	160	165	160	51	57
Vehicle Delay (s)	241	203	305	315	17	16
Vehicle Travel Time (s)	389	382	395	379	382	385

4.1 Maximum Queue Length

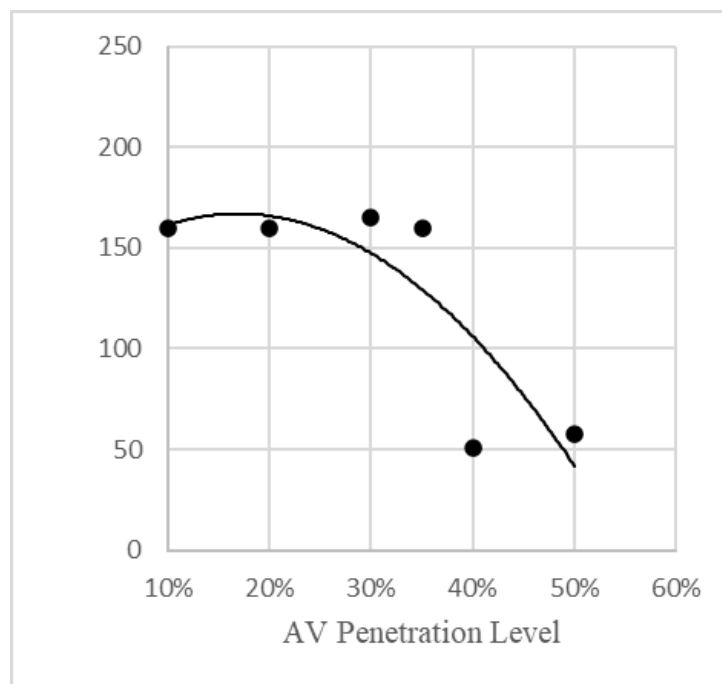
A vehicle is considered in a queued condition if its speed drops below the initial speed threshold of 2 km/h and has not yet exceeded the final speed threshold of 5 km/h. The Maximum Queue Length is defined as the sum of the Maximum Queue Lengths observed in curbside and through traffic lanes, serving as a measure of roadway congestion. The current queue length is measured upstream in meters at each time step,

and the maximum value is computed over each time interval. Figure 4.1 presents a summary of results in terms of Maximum Queue Lengths.

As autonomous vehicle (AV) penetration levels increase from 10% to 35%, the impact on Maximum Queue Length shows minimal variation. However, a notable decrease in Maximum Queue Length is observed when penetration levels exceed 35%.

Figure 4.1

Maximum Queue Length



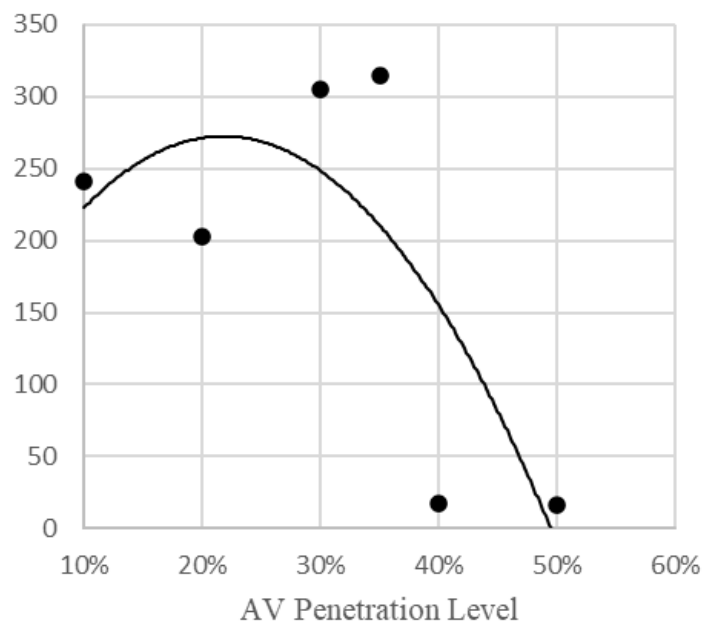
4.2 Vehicle Delay

To determine the total delay for each vehicle, the actual time taken to travel through a specific section is subtracted from the theoretical (ideal) travel time. The theoretical travel time reflects the duration a vehicle would take if no other vehicles, signal controls, or network stops were present, while accounting for reduced speed zones. This delay measurement excludes time spent by passengers at transit stops but includes time lost due to acceleration or deceleration associated with these stops. A summary of the results related to Vehicle Delay is illustrated in Figure 4.2.

Vehicle Delay does not exhibit a consistent trend of increase or decrease as the autonomous vehicle (AV) penetration level increases from 10% to 35%. However, there is a significant reduction in Vehicle Delay as the penetration level increases beyond 35%. Between 40% and 50% penetration, Vehicle Delay reaches zero.

Figure 4.2

Vehicle Delay



4.3 Vehicle Travel Time

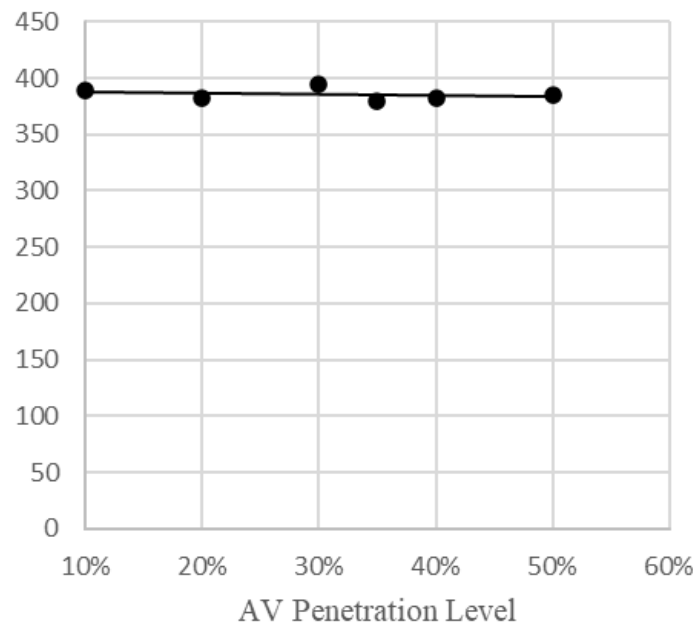
PTV VISSIM can assess average travel times if travel time sections are established within the network. Each section is defined by a start and a destination cross-section. The average travel time, which includes waiting or dwell times, is calculated as the duration a vehicle takes to move from the first cross-section to the second.

In this simulation, the travel time section corresponds to a curbside length of 122 meters. Figure 4.3 summarizes the results concerning vehicle travel times, showing

that different levels of autonomous vehicle (AV) penetration did not significantly affect the travel times.

Figure 4.3

Vehicle Travel Time



4.4 Discussion

Figure 4.1 and Figure 4.2 demonstrate analogous trends concerning the impact of varying Autonomous Vehicle (AV) penetration levels. Up to a penetration level of 35%, both Maximum Queue Length and Vehicle Delay show negligible changes. However, beyond this threshold, substantial reductions are evident (68% decrease in maximum queue length and a 95% decrease in Vehicle Delay). Consistent findings from prior research cited in the literature, focusing on urban roads and highways, suggest that AV effects are less pronounced below a 40% penetration level.

Given the network design employed in this study, which separate lanes for Human Driven Vehicles (HDVs) and AVs, it is recommended to model traffic flow scenarios with AV penetration levels set at 35%, 40%, and 50% under mixed traffic conditions, without separated lanes, to determine the optimal AV penetration level for curbside operations at airports.

Figure 4.3, illustrating Vehicle Travel Time, shows no visible changes in response to varying AV penetration levels. Therefore, it can be concluded that Vehicle Travel Time remains unaffected by the introduction of AVs. This model has not captured some of the complexities of real-world airport curbside operations, such as passenger and pedestrian behaviours. AVs and HDVs in this study operate in a relatively controlled environment, which may explain the lack of significant change in vehicle travel time with the increase in AV penetration.

A notable enhancement in traffic flow, as indicated by reductions in Maximum Queue Length and Vehicle Delay, becomes apparent when autonomous vehicles (AVs) constitute more than 35% of the vehicle fleet. The Literature Review underscores that AVs contribute to improved traffic flow through several key mechanisms:

- **Reduction in Traffic Jams:** With AVs, there is a reduction in the stop-and-go nature of traffic caused by human drivers. For instance, AVs can maintain a steady flow, and handle merges and lane changes more smoothly, reducing the ripple effect of congestion.
- **Efficient Use of Road Space:** AVs can communicate with each other and with traffic infrastructure (e.g., traffic lights, sensors) to optimize their movements. This coordination allows for tighter and more efficient spacing between vehicles, which helps in reducing congestion and improving overall traffic flow.
- **Optimized Traffic Behavior:** AVs are programmed to follow traffic rules meticulously, maintain optimal speeds, and avoid aggressive driving behaviors. This consistent and predictable behavior reduces instances of sudden braking, abrupt lane changes, and tailgating, which can lead to smoother traffic flow.

•**Improved Traffic Management:** AVs can be integrated into smart traffic management systems that adjust signal timings and traffic control measures based on real-time data. This dynamic adjustment helps in managing traffic flow more effectively, reducing delays and bottlenecks.

•**Enhanced Safety:** AVs reduce accidents caused by human error, which in turn decreases the frequency and severity of traffic incidents. Fewer accidents lead to fewer traffic jams and smoother flow of traffic.

It is important to note that the microsimulation model utilized in this study does not include features such as Vehicle-to-Vehicle (V2V) communication, which limits the potential impact of AVs in this model. Consequently, the improvement in traffic flow attributed to AVs in this model is primarily due to the reduction of traffic jams caused by the irregular stop-and-go behavior of human drivers.

The threshold of 35% AVs is identified as a critical point where the cumulative benefits of these factors become substantial enough to achieve a noticeable improvement in traffic flow. Below this threshold, the impact of AVs may be less significant due to the predominance of human-driven vehicles, which introduce variability and inefficiencies into the traffic system.

CHAPTER 5

5.1 Limitations of the study

This microsimulation study on Automated Vehicle (AV) penetration in curbside operations at airports offers valuable insights into how AVs might impact traffic flow and operational efficiency. However, this study also has several limitations that could affect the accuracy and generalizability of the findings.

- **Complexity of Airport Operations**

- a. **Airport-specific factors:** Airports are complex environments with unique traffic patterns, multiple modes of transport (e.g., taxis, buses, shuttles), and a mix of pedestrian and vehicle traffic. This microsimulation study has not fully captured all the operational nuances, such as security checks, luggage handling, or time-of-day fluctuations, which can significantly affect curbside operations.
- b. **Dynamic nature of curbside operations:** Curbside operations are often highly dynamic, with rapidly changing factors like fluctuating passenger volumes, event-driven congestion, or emergency situations. This study has not captured passenger and pedestrian behaviors. Therefore, AVs and HDVs in this study operate in a relatively controlled environment.

- **Limitations in Modeling AV Behavior**

This simulation does not fully account for all AV technologies, such as Vehicle to Vehicle communication, different sensor capabilities, or AVs' adaptive decision-making in uncertain environments. For instance, AVs might face challenges in crowded, highly dynamic environments like an airport curbside.

- **Challenges in adopting a designated AV lane network at airport**

One of the primary challenges in adopting a designated Autonomous Vehicle (AV) lane network at airports is the limitation of landside space. Given the spatial constraints, it is essential to conduct a thorough cost-benefit analysis to determine whether the benefits of such infrastructure outweigh the associated costs and space requirements.

The feasibility of implementing AV specific lanes also hinges on the anticipated volume of AV traffic at the airport. In scenarios where AV adoption is low, the demand for designated lanes may not justify the financial investment or the allocation of scarce land resources. Conversely, in regions with higher AV adoption such as proximity to technology hubs or cities with advanced transportation systems. This type of infrastructure may be more practical and worthwhile.

In airports with limited landside space, an alternative approach might be to prioritize the enhancement of the overall traffic management system rather than dedicating space for AV-specific lanes. Improving existing traffic flow and optimizing vehicle and passenger movement across various modes of transport could offer a more efficient and cost-effective solution.

- **Absence of merging and diverging traffic analysis**

This study has intentionally simplified the broader traffic network to focus on key variables directly related to the research. AV lane performance at an airport curbside does prioritize factors like vehicle capacity, roadway congestion resulting from vehicles occupying through lanes, vehicles waiting to access the curbside roadway, rather than the complexities of merging and diverging traffic which may occur further downstream in the transportation system.

Since the road network within the simulation is relatively straightforward such as dedicated lanes for AVs that do not involve complex interchanges or intersection the behavior of merging and diverging traffic may not significantly impact the simulation's results.

- **Model Calibration and Validation**

Microsimulations must be calibrated to real-world observations. However, calibrating this model to reflect the behavior of AVs in an airport environment could be difficult, since AVs have not yet been extensively deployed in that context. Any miscalibration can lead to inaccurate results.

Even with a well-calibrated model, it may be challenging to validate the results, since the simulation predicts a future scenario (e.g. AV penetration rates from 10% to 50%) that has not yet been realized. Without real-world validation data, it is hard to know how accurate or reliable the simulation findings are.

Future studies on AVs in airport settings should prioritize the use of real-world data from ongoing AV trials and pilot programs to refine and calibrate simulation models. By collecting data on how AVs interact with other vehicles, pedestrians, and infrastructure under actual operating conditions, researchers can improve the accuracy of their simulations. Collaboration with AV manufacturers and operators is essential to gain more detailed insights into AV capabilities, including sensor reliability, decision-making algorithms, and human-AV interactions.

To ensure the validity of simulation results, future studies should focus on collecting empirical data from these AV trials at airports and compare the results with real-world outcomes. In addition to this, researchers can apply simulation-based validation methods, such as cross-validation with other models or testing under various scenarios, to assess the robustness and reliability of the models.

Another crucial area for future studies is the development of more detailed behavioral models for both AVs and human drivers. Using machine learning techniques, researchers can simulate more realistic interactions based on observed real-world data and account for the variability in human behavior. Additionally, AVs' ability to predict and respond to human driver behavior should be further studied and incorporated into the simulation.

Moreover, future models could be enhanced by including more complex traffic interactions, such as merging and diverging traffic, congestion points, and emergency situations. Expanding the scope of the simulation to cover a broader network of airport roads will allow researchers to analyze how AVs perform under various conditions, providing a more comprehensive understanding of AV behavior and their impact on airport traffic.

5.2 Conclusion

The impact of Autonomous Vehicles (AVs) on traffic flow has garnered significant attention, particularly in anticipation of their widespread integration into road networks in the future. However, the potential ramifications of AVs on airport curbside and internal roadway operations remain largely unexplored. This study aimed to investigate how curbside operations may evolve with varying percentages of AVs in circulation.

Utilizing a conceptual network combined with a microsimulation method through VISSIM, this study aims to precisely replicate vehicle behaviors. To improve safety in traffic flow, separate curbside lanes were designated for Human-Driven Vehicles (HDVs) and AVs, aligning with prior research indicating the advantages of AV-only lanes, particularly in merging and diverging highway sections, when AV penetration rates remain below 40%.

Parameters governing AV behaviors were set at SAE level 4, based on previous studies, albeit without incorporating certain AV features such as Vehicle-to-Vehicle (V2V) communication into the simulation.

Six scenarios were simulated, each representing incremental increases in AV penetration rates from 10% to 50%. Total vehicle flow (comprising AVs and HDVs) remained constant across all scenarios.

The study investigated traffic flow improvements in terms of Maximum Queue Lengths, Vehicle Delay, and Vehicle Travel Time. While AVs demonstrate potential for enhancing traffic flow, the results indicate that their impact is not significant when penetration levels are below 35%. Thus, the study concludes that discernible improvements in curbside traffic flow at airports are only observable once AV penetration levels surpass 35%.

Furthermore, the study reveals that AV penetration levels beyond 35% lead to substantial improvements in traffic flow metrics, such as a 68% reduction in Maximum Queue Length and a 95% reduction in Vehicle Delay when penetration levels increase

from 35% to 40%. However, further increases in AV penetration result in diminishing traffic flow improvements, suggesting an optimal penetration level between 35% and 50%.

The observed improvement in traffic flow attributed to autonomous vehicles (AVs) in this model can be primarily credited to their ability to mitigate the stop-and-go nature of traffic caused by human drivers. By maintaining a steady flow and handling mergers and lane changes more smoothly, AVs effectively reduce the ripple effect of congestion, thereby enhancing overall traffic flow.

The 35% threshold of autonomous vehicles (AVs) has been identified as a pivotal point at which the cumulative advantages of these vehicles become significant enough to produce a noticeable improvement in traffic flow. When the proportion of AVs is below this threshold, their impact on traffic flow may be less pronounced. This is primarily due to the continued predominance of human-driven vehicles, which introduce variability and inefficiencies into the traffic system.

Future studies on AVs in airports should use real-world data from ongoing AV trials to improve simulation accuracy. Collaboration with AV manufacturers will provide insights into AV capabilities, including sensor reliability and human-AV interactions. Studies should validate simulations by comparing results with real-world data and incorporate machine learning to model realistic AV-human driver behavior. Additionally, expanding simulations to include complex traffic interactions, such as merging, diverging, and congestion, will provide a more comprehensive understanding of AV performance in airport environments.

The study recommends simulating traffic flow scenarios with AV penetration levels set at 35%, 40%, and 50% under mixed traffic conditions, without delineating separate lanes for AVs and HDVs, to ascertain the optimal AV penetration level for curbside operations at airports.

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APPENDICES

Appendix A: Microsimulation model results for 10% AV penetration

Table A.1

Node Results

MOVEMENT	QLEN	QLEN MAX	VEHS (ALL)	LOS (ALL)	VEH DELAY (ALL)
1	87	147	311	LOS_F	224
2	9	13	310	LOS_C	15
3	0	0	44	LOS_A	0
4	0	0	44	LOS_A	1

Table A.2

Queue counter Results

QUEUE COUNTER	QLEN	QLEN MAX	Q STOPS
1	111	171	624
2	0	8	3

Table A.3

Vehicle Travel Time Results

VEHICLE TRAVEL TIME MEASUREMENT	VEHS (ALL)	TRAV TM (ALL)	DIST TRAV (ALL)
1	312	220	122
2	41	170	122

Table A.4*Link Segment Results*

TIME INT	LINK EVAL SEGMENT	DENSITY (ALL)	DELAY REL (ALL)	SPEED (ALL)	VOLUME (ALL)
1800- 5400	1-1-0-144	1.03	56.30%	23.39	23.99
1800- 5400	1-2-0-144	13.2	6.83%	1.25	16.52
1800- 5400	2-1-0-143	41.39	81.65%	5.98	247.52
1800- 5400	2-2-0-143	115.28	22.67%	0.43	49.28
1800- 5400	3-1-0-142	0.84	7.24%	49.38	41.67
1800- 5400	3-2-0-142	0.07	50.12%	27.22	1.79
1800- 5400	4-1-0-142	90.11	95.05%	1.6	143.84
1800- 5400	4-2-0-142	86.81	93.48%	2.11	183.44
1800- 5400	5-1-0-19	0.43	0.00%	50.97	22.01
1800- 5400	5-2-0-19	0.31	0.00%	52.11	16.27
1800- 5400	7-1-0-19	8.35	-0.23%	32.72	273.15
1800- 5400	7-2-0-19	0.68	-2.26%	35.24	23.79
1800- 5400	10000-1-0-14	0.66	23.83%	40.77	26.79
1800- 5400	10000-2-0-14	0.62	47.14%	27.65	17.21
1800- 5400	10001-1-0-17	130.46	97.12%	0.94	122.14
1800- 5400	10001-2-0-17	142.71	95.93%	1.32	188.79
1800- 5400	10002-1-0-11	0.46	0.00%	51.46	23.65
1800- 5400	10002-2-0-11	0.32	0.00%	52.75	17
1800- 5400	10003-1-0-14	8.64	-0.95%	33.2	287
1800- 5400	10003-2-0-14	0.76	3.08%	32.78	25

Appendix B: Microsimulation model results for 20% AV penetration

Table B.1

Node Results

MOVEMENT	Q LEN	QLEN MAX	VEHS (ALL)	LOS (ALL)	VEH DELAY (ALL)
1	59	147	288	LOS_F	189
2	8	13	287	LOS_B	13
3	0	0	82	LOS_A	0
4	0	0	82	LOS_A	0

Table B.2

Queue counter Results

QUEUE COUNTER	QLEN	QLEN MAX	Q STOPS
1	81.2	171.47	496
2	0.21	9.37	9

Table B.3

VTT Results

VTT MEASUREMENT	VEHS (ALL)	TRAV TM (ALL)	DIST TRAV (ALL)
1	285	208.9	122
2	82	173.53	122

Table B.4*Link Segment Results*

TIME INT	LINK EVAL SEGMENT	DENSITY (ALL)	DELAY REL (ALL)	SPEED (ALL)	VOLUME (ALL)
1800- 5400	1-1-0-144	2.2	48.37%	27.54	60.54
1800- 5400	1-2-0-144	25.6	4.69%	0.73	18.74
1800- 5400	2-1-0-143	37.38	80.81%	6.24	233.35
1800- 5400	2-2-0-143	103.42	20.83%	0.41	42.07
1800- 5400	3-1-0-142	1.56	5.63%	49.7	77.56
1800- 5400	3-2-0-142	0.1	35.34%	33.95	3.41
1800- 5400	4-1-0-142	61.66	91.08%	2.87	177.25
1800- 5400	4-2-0-142	57.62	93.17%	2.2	126.99
1800- 5400	5-1-0-19	1.2	0.00%	51.07	61.26
1800- 5400	5-2-0-19	0.33	0.00%	51.45	17.23
1800- 5400	7-1-0-19	7.55	-0.03%	32.53	245.55
1800- 5400	7-2-0-19	0.73	-2.19%	35.31	25.7
1800- 5400	10000-1-0-14	1.16	16.24%	44.12	51.01
1800- 5400	10000-2-0-14	1.1	46.06%	28.13	30.99
1800- 5400	10001-1-0-17	114.12	95.71%	1.39	158.76
1800- 5400	10001-2-0-17	139.31	97.14%	0.93	129.02
1800- 5400	10002-1-0-11	1.24	0.00%	51.6	64
1800- 5400	10002-2-0-11	0.35	0.00%	52.16	18
1800- 5400	10003-1-0-14	7.88	-0.10%	32.75	258
1800- 5400	10003-2-0-14	0.78	-1.29%	34.5	27

Appendix C: Microsimulation model results for 30% AV penetration

Table C.1

Node Results

MOVEMENT	QLEN	QLEN MAX	VEHS (ALL)	LOS (ALL)	VEH DELAY (ALL)
1	78	147	269	LOS_F	282
2	10	13	271	LOS_C	22
3	0	6	116	LOS_A	0
4	0	0	116	LOS_A	0

Table C.2

Queue counter Results

QUEUE COUNTER	QLEN	QLEN MAX	Q STOPS
1	103	171	469
2	0	20	13

Table C.3

VTT Results

VTT MEASUREMENT	VEHS (ALL)	TRAV TM (ALL)	DIST TRAV (ALL)
1	264	210	122
2	121	185	122

Table C.4*Link Segment Results*

TIME INT	LINK EVAL SEGMENT	DENSITY (ALL)	DELAY REL (ALL)	SPEED (ALL)	VOLUME (ALL)
1800- 5400	1-1-0-144	4.05	56.40%	23.37	94.71
1800- 5400	1-2-0-144	39.19	8.64%	0.56	22.01
1800- 5400	2-1-0-143	36.1	81.41%	5.99	216.17
1800- 5400	2-2-0-143	93.68	22.80%	0.45	42.39
1800- 5400	3-1-0-142	2.18	6.90%	49.09	106.98
1800- 5400	3-2-0-142	0.25	43.21%	30.31	7.61
1800- 5400	4-1-0-142	78.07	93.76%	2.01	157.28
1800- 5400	4-2-0-142	79.72	95.30%	1.53	121.91
1800- 5400	5-1-0-19	1.87	0.04%	51.71	96.67
1800- 5400	5-2-0-19	0.37	0.03%	51.33	19.14
1800- 5400	7-1-0-19	6.95	0.09%	32.36	224.85
1800- 5400	7-2-0-19	0.75	-1.86%	35.15	26.41
1800- 5400	10000-1-0-14	1.89	20.53%	42.08	79.57
1800- 5400	10000-2-0-14	1.96	64.39%	18.57	36.43
1800- 5400	10001-1-0-17	139.18	96.68%	1.08	150.04
1800- 5400	10001-2-0-17	156.44	97.63%	0.77	119.96
1800- 5400	10002-1-0-11	1.93	0.00%	52.38	101
1800- 5400	10002-2-0-11	0.38	0.05%	51.96	20
1800- 5400	10003-1-0-14	7.35	0.26%	32.25	237
1800- 5400	10003-2-0-14	0.77	-2.85%	35.13	27

Appendix D: Microsimulation model results for 35% AV penetration

Table D.1

Node Results

MOVEMENT	QLEN	QLEN MAX	VEHS (ALL)	LOS (ALL)	VEH DELAY (ALL)
1	74	147	106	LOS_F	290
2	9	13	106	LOS_C	24
3	0	0	75	LOS_A	0
4	0	0	75	LOS_A	0

Table D.2

Queue counter Results

QUEUE COUNTER	QLEN	QLEN MAX	Q STOPS
1	99	172	259
2	1	13	14

Table D.3

VTT Results

VTT MEASUREMENT	VEHS (ALL)	TRAV TM (ALL)	DIST TRAV (ALL)
1	107	204	122
2	73	175	122

Table D.4*Link Segment Results*

TIME INT	LINK EVAL SEGMENT	DENSITY (ALL)	DELAY REL (ALL)	SPEED (ALL)	VOLUME (ALL)
900- 2700	1-1-0-144	4.51	49.45%	27.09	122.22
900- 2700	1-2-0-144	46.19	5.96%	0.43	20.02
900- 2700	2-1-0-143	29.21	81.44%	6.05	176.62
900- 2700	2-2-0-143	76.23	25.93%	0.42	31.72
900- 2700	3-1-0-142	2.75	6.44%	49.28	135.6
900- 2700	3-2-0-142	0.4	39.70%	31.59	12.56
900- 2700	4-1-0-142	73	94.01%	1.93	141.08
900- 2700	4-2-0-142	75.68	95.89%	1.33	100.96
900- 2700	5-1-0-19	2.36	0.00%	51.83	122.51
900- 2700	5-2-0-19	0.34	0.00%	51.24	17.23
900- 2700	7-1-0-19	5.66	0.04%	32.11	181.7
900- 2700	7-2-0-19	0.64	0.00%	31.19	20.06
900- 2700	10000-1-0-14	2.44	16.40%	43.98	107.35
900- 2700	10000-2-0-14	1.71	52.68%	24.88	42.65
900- 2700	10001-1-0-17	153.88	97.38%	0.85	130.92
900- 2700	10001-2-0-17	162.14	98.42%	0.51	82.02
900- 2700	10002-1-0-11	2.44	0.00%	52.48	128
900- 2700	10002-2-0-11	0.35	0.00%	51.98	18
900- 2700	10003-1-0-14	5.93	0.09%	32.36	192
900- 2700	10003-2-0-14	0.62	0.00%	32.13	20

Appendix E: Microsimulation model results for 40% AV penetration

Table E.1

Node Results

MOVEMENT	QLEN	QLEN MAX	VEHS (ALL)	LOS (ALL)	VEH DELAY (ALL)
1	2	20	248	LOS_A	10
2	3	13	248	LOS_A	6
3	0	17	166	LOS_A	1
4	0	0	168	LOS_A	1

Table E.2

Queue counter Results

QUEUE COUNTER	QLEN	QLEN MAX	Q STOPS
1	13	45	132
2	1	32	22

Table E.3

VTT Results

VTT MEASUREMENT	VEHS (ALL)	TRAV TM (ALL)	DIST TRAV (ALL)
1	253	209	122
2	155	172	122

Table E.4*Link Segment Results*

TIME INT	LINK EVAL SEGMENT	DENSITY (ALL)	DELAY REL (ALL)	SPEED (ALL)	VOLUME (ALL)
1800- 5400	1-1-0-144	6.04	59.50%	21.7	131.16
1800- 5400	1-2-0-144	50.56	7.10%	0.44	22.35
1800- 5400	2-1-0-143	22.29	70.38%	9.57	213.3
1800- 5400	2-2-0-143	85.76	13.80%	0.33	28.46
1800- 5400	3-1-0-142	3.19	11.61%	46.64	148.93
1800- 5400	3-2-0-142	0.6	44.71%	28.62	17.22
1800- 5400	4-1-0-142	7.37	14.29%	27.24	200.78
1800- 5400	4-2-0-142	2.89	51.68%	15.34	44.26
1800- 5400	5-1-0-19	2.46	0.07%	52.05	128.25
1800- 5400	5-2-0-19	0.38	0.00%	53.38	20.1
1800- 5400	7-1-0-19	6.88	0.02%	32.24	221.75
1800- 5400	7-2-0-19	0.56	-1.69%	34.11	19.03
1800- 5400	10000-1-0-14	2.95	23.30%	40.53	119.66
1800- 5400	10000-2-0-14	8.15	88.96%	5.78	47.09
1800- 5400	10001-1-0-17	12.24	68.02%	10.21	125.01
1800- 5400	10001-2-0-17	62.24	93.89%	1.98	122.94
1800- 5400	10002-1-0-11	2.54	0.07%	52.72	134
1800- 5400	10002-2-0-11	0.39	0.00%	54.02	21
1800- 5400	10003-1-0-14	7.2	-0.01%	32.37	233
1800- 5400	10003-2-0-14	0.57	-3.59%	35.38	20

Appendix F: Microsimulation model results for 50% AV penetration

Table F.1

Node Results

MOVEMENT	QLEN	QLEN MAX	VEHS (ALL)	LOS (ALL)	VEH DELAY (ALL)
1	1	19	214	LOS_A	6
2	2	13	212	LOS_A	3
3	1	19	206	LOS_A	5
4	0	6	206	LOS_A	3

Table F.2

Queue counter Results

QUEUE COUNTER	QLEN	QLEN MAX	Q STOPS
1	7	43	92
2	4	35	34

Table F.3

VTT Results

VTT MEASUREMENT	VEHS (ALL)	TRAV TM (ALL)	DIST TRAV (ALL)
1	203	198	122
2	199	187	122

Table F.4*Link Segment Results*

TIME INT	LINK EVAL SEGMENT	DENSITY (ALL)	DELAY REL (ALL)	SPEED (ALL)	VOLUME (ALL)
1800- 5400	1-1-0-144	9.6	67.02%	17.63	169.22
1800- 5400	1-2-0-144	67.18	10.96%	0.43	28.63
1800- 5400	2-1-0-143	14.52	62.98%	12	174.26
1800- 5400	2-2-0-143	68.88	10.31%	0.37	25.23
1800- 5400	3-1-0-142	3.95	14.20%	45.1	177.93
1800- 5400	3-2-0-142	1.18	58.78%	21.61	25.54
1800- 5400	4-1-0-142	6.18	10.22%	28.61	176.67
1800- 5400	4-2-0-142	1.89	39.45%	18.98	35.94
1800- 5400	5-1-0-19	3.1	0.03%	52.47	162.69
1800- 5400	5-2-0-19	0.52	-0.43%	53.7	27.76
1800- 5400	7-1-0-19	5.47	0.00%	32.04	175.12
1800- 5400	7-2-0-19	0.56	0.00%	32.33	18.08
1800- 5400	10000-1-0-14	4.51	39.84%	31.76	143.33
1800- 5400	10000-2-0-14	22.29	94.62%	2.81	62.67
1800- 5400	10001-1-0-17	9.85	66.49%	10.59	104.32
1800- 5400	10001-2-0-17	37.25	90.99%	2.92	108.87
1800- 5400	10002-1-0-11	3.2	0.01%	53.17	170
1800- 5400	10002-2-0-11	0.53	-1.03%	54.42	29
1800- 5400	10003-1-0-14	5.68	-0.03%	32.42	184
1800- 5400	10003-2-0-14	0.57	0.00%	33.5	19