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16. Abstract:

Currently, ports are playing an important role in the national economy of the USA. On the other hand, truck operation is an essential part for ports' activities. However, a higher transportation cost and time within a port facility can increase overall expenditures for a wholesale organization. Especially, an increased transportation time may result in higher inventory costs for a company along with opportunity cost. It is well developed that the operation of AGV accompanied with a platooning system in place of the conventional heavy trucks operation will reduce the dwelling time which will also positively impact the transportation costs.

To improve the port efficiency, this project proposes operations of automated ground vehicle (AGV) along with the platooning tool within the port facility as this system is capable of reducing dwell time, which leads to a reduction in opportunity cost. The project is also focusing on lowering emissions from the proposed AGV, which will result in lower greenhouse gas (GHG) emissions. To reduce the emission of GHG, the decarbonation concept can be implemented for the planned AGV system in port. Electrification is one of the primary factors considered for the transportation industry's decarbonization strategy. However, production of electricity itself can emit large amounts of CO2. Therefore, the vehicle to grid (V2G) technique can be implemented within a port facility. The proposed AGV's batteries can be charged within the grid, where it can also be used as a backup for the electric grid. As a result, the reliance on burning fossil fuels to generate electricity will be reduced, resulting in lower carbon emissions. In addition, renewable energy systems (e.g. solar panels, wind turbines etc.) can be employed to produce electricity for the grid. The study intends to accomplish its objectives by developing and solving multi-objective mixed integer linear programming optimization problems, such as determining the optimal number of AGV to reduce transportation costs and times, as well as GHG emissions from the AGV, and ensuring equity for heavy truck drivers. This research will help government officials, logistics service providers, and other relevant decision makers plan for long-term urban logistics.

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CONCEPT OF OPERATIONS FOR HEAVY TRUCK OPERATIONS IN/AROUND THE PORTS TO IMPROVE EFFICIENCY AND SUPPORT CLIMATE SOLUTIONS

FINAL REPORT

by

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EXECUTIVE SUMMARY

Currently, ports are playing an important role in the national economy of the USA. On the other hand, truck operation is an essential part for ports' activities. However, a higher transportation cost and time within a port facility can increase overall expenditures for a wholesale organization. Especially, an increased transportation time may result in higher inventory costs for a company along with opportunity cost. It is well developed that the operation of AGV accompanied with a platooning system in place of the conventional heavy trucks operation will reduce the dwelling time which will also positively impact the transportation costs.

At present, global warming is a prime concern for the world population and greenhouse gas (GHG) emissions are a major contributor to this situation Port is one of the prime sources of the GHG as port activities alone account for 3% of global carbon emissions while heavy-duty trucks emit around 40% of a port's total greenhouse gasses. Although ships are the significant contributor of the GHG emissions from port, heavy truck operation can also have considerable impacts. The main reasons for the GHG emissions are burning fossil fuels to operate the heavy vehicle. When fossil fuels are burned, a large amount of carbon dioxide (CO2) is released into the atmosphere. Electrification of the heavy duty truck vehicles can be a potential concept to reduce the impact of ports on global warming issues. However, generation of electricity can also produce a large amount of GHG. This problem can be mitigated by implementing V2G technology in conjunction with renewable energy systems such as solar panels. According to this concept, electricity will be generated using the suggested renewable energy system while V2G technology will ensure that charging batteries can also be used as a back-up for the grid.

Ensuring equity within port facilities has become an important issue. Establishment of equity refers not only to minimizing racial injustice and promoting working protocols to support historically backward populations but also ensuring an employee-friendly working environment. The later factor consists of creating a work plan which will ascertain employee satisfaction. In case of port operations, queuing and waiting for loading/unloading can influence the risk of fatigue for heavy truck drivers if it extends work hours or restricts drivers' access to rest. The current study proposes a sophisticated truck appointment system (TAS) which may reduce the chances of exhaustion for a driver by lowering their waiting time during the operation period. This is due to the fact that this approach makes it possible for a driver to know in advance that they can perform the desired number of visits to the port even without early arrivals.

To improve the port efficiency, this project proposes operations of automated ground vehicle (AGV) along with the platooning tool within the port facility as this system is capable of reducing dwell time, which leads to a reduction in opportunity cost. The project is also focusing on lowering emissions from the proposed AGV, which will result in lower greenhouse gas (GHG) emissions. To reduce the emission of GHG, the decarbonation concept can be implemented for the planned AGV system in port. Electrification is one of the primary factors considered for the transportation industry's decarbonization strategy. However, production of electricity itself can emit large amounts of CO2. Therefore, the vehicle to grid (V2G) technique can be implemented within a port facility. The proposed AGV's batteries can be charged within the grid, where it can also be used as a backup for the electric grid. As a result, the reliance on burning fossil fuels to generate electricity will be reduced, resulting in lower carbon emissions. In addition, renewable energy systems (e.g. solar panels, wind turbines etc.) can be employed to produce electricity for the grid. Furthermore, the management of queuing and waiting for loading/unloading in the port can influence the risk of fatigue for heavy truck drivers if it extends work hours or makes resting

difficult for drivers, which is considered a part of equity for the port operation. Thus, the current study proposes a truck appointment system (TAS) in which drivers will be assigned to specific heavy trucks moving out of ports, ensuring that trips are completed within their assigned working hours. The study intends to accomplish its objectives by developing and solving multi-objective mixed integer linear programming optimization problems, such as determining the optimal number of AGV to reduce transportation costs and times, as well as GHG emissions from the AGV, and ensuring equity for heavy truck drivers. This research will help government officials, logistics service providers, and other relevant decision makers plan for long-term urban logistics.

Key Findings

- The study enhances heavy truck operations, reduces congestion, and mitigates environmental impacts, providing practical insights through a Port of Miami case study.
- The developed microsimulation model supports real-world traffic scenarios, adaptable to various ports and capable of analyzing future traffic and rail freight systems.
- Incorporates automation, electrification, and sustainable practices to optimize terminal operations, last-mile delivery, and truck scheduling systems for enhanced efficiency and sustainability.
- Explores solutions like signal timing optimization, congestion pricing, and expanded traffic scenarios to improve port logistics and supply chain resilience.

Key Recommendations

- Extend the proposed methodologies to optimize terminal operations, incorporate sustainable last-mile delivery solutions, and integrate truck automation and electrification technologies.
- Explore advanced strategies like signal timing optimization, congestion pricing, and improved scheduling systems for truck stops and rest areas to mitigate congestion and enhance freight movement.
- Tailor the operational concept to address unique challenges of other ports, extending the microsimulation model inside and outside port areas, including freeways and arterials.
- Leverage trends in the transportation industry, such as electrification and autonomous vehicle technologies, to reduce emissions, improve efficiency, and ensure sustainability.

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1. Introduction

An intermodal facility is intended to facilitate the efficient movement of a shipment from one mode of transportation to another as it travels from origin to destination. This concept is essential to intermodal freight transport, which entails transporting freight in an intermodal container or vehicle over numerous modes of transportation (e.g., rail, ship, and truck) without any handling of the freight itself when changing modes (The Role of the National Highway System Connectors - FHWA Freight Management and Operations, 2020; Intermodal Facility Definition: Law Insider, n.d.). For example, Ports serve as essential intermodal terminals and transport hubs, facilitating the movement of goods to businesses in local communities and across international markets. The ports of the United States are vital to the nation's competitive edge, as they serve as the primary entry point for 99.9% of international trade and generate $5.4 trillion in economic activity or approximately 26% of the U.S. economy. More than 300 ports in the United States serve as major economic drivers and employment centers (America's Infrastructure Report Card 2021 | GPA: C-, n.d.).

Worldwide, the transportation infrastructure for transferring cargo to and from ports and the regions they service is challenging to keep up with current cargo quantities. These numbers are projected to increase higher. Port logistics includes a wide range of activities, including cargo handling, loading and unloading, customs documentation, monitoring, and more. Thus, success in global trade and transactions necessitates efficient port logistics operations. Containers accumulate at various U.S. port terminals due to transportation bottlenecks, resulting in costly delays and more significant fuel expenses for rescheduling and compensating for lost time. A problem in one place can affect everything from ports to transport carriers all over the supply chain, making things cost more for everyone. These disruptions significantly impact lean manufacturing approaches, designed to minimize manufacturing waste, and just-in-time delivery systems to lower inventory and distribution costs. As a result of these hold-ups, importers face considerable costs, and the predictability and reliability of the supply chain are severely compromised. (ICC, 2005).

The transportation industry contributes significantly to the U.S. economy. For many years, it has been at the forefront of supply chain operations in the country. In the United States, approximately 72.5% of the nation's total freight by weight, or 10.93 billion tons, is transported by trucks. This demonstrates the importance of their function in delivering goods and products. Every item used in the United States is transported at some stage by truck. The trucking industry is anticipated to experience substantial growth in the coming years, resulting in an anticipated increase in revenue (The Transwest Team, 2022). Figure 1 illustrates the persistent rise in registered trucks in the United States since 1995, reinforcing the industry's vital role in the economy.

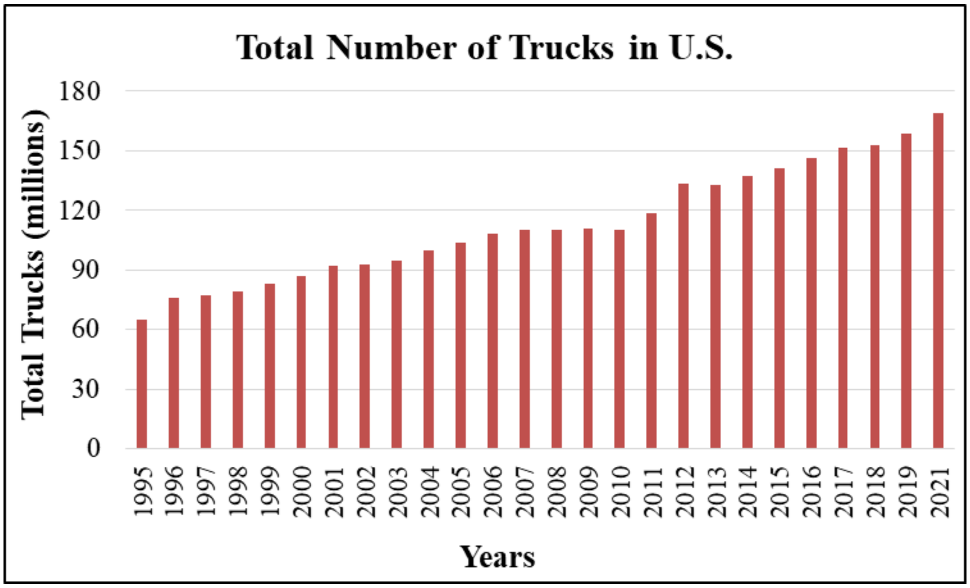

Figure 1: Total number of Registered Trucks in the U.S. over the past decades (Source: U.S. Department of Transportation, Federal Highway Administration, Highway Statistics, 2021)

According to Figure 1, the number of trucks registered in the United States increased by 93.5 percent between 2000 and 2021. In 2021, over 168.6 million public, private, and commercial trucks were registered in the United States. In the context of port heavy truck operations in the United States, heavy trucks are crucial in moving goods from U.S. ports to their final destinations. However, growing cargo volumes and increased port congestion cause longer waiting times and more fuel use. To address these challenges, we require innovative solutions and improved infrastructure for managing heavy vehicle traffic around ports. This could include dedicated truck lanes, traffic management systems, and better communication between trucks, ports, and other personnel involved. The United States can increase its global competitiveness and maintain efficient port operations by addressing these concerns.

1.1 Environmental Impact and Equity Situation

Global warming, primarily driven by greenhouse gas (GHG) emissions, is a paramount concern for humanity today. A substantial portion of these emissions are attributable to the expansion of the global freight transportation sector, which significantly relies on diesel fuel combustion, which by nature produces greenhouse gases. Specifically, heavy-duty trucks, rail, and marine transportation account for more than 25 percent of all other sources of CO2 emissions in the United States (Corbett & Winebrake, 2007).

The primary factor behind these GHG emissions is the utilization of fossil fuels to power large vehicles. For example, in 2019, the three most important ports in the U.S. are Los Angeles, Long Beach, and New York and New Jersey - which contributed to over 2.5 million tons of carbon dioxide equivalent (CO2e) emissions (Bertrand & Williams, 2022). Figure 2 presents the different amounts of emissions produced by various port activities, including ocean-going vessels, harbor crafts, cargo handling equipment, trains, and heavy-duty vehicles.

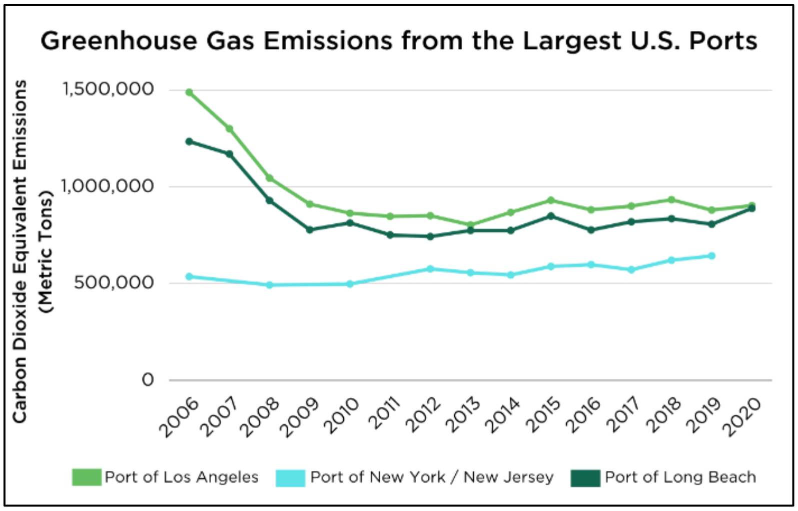

Figure 2: Greenhouse Gas Emissions from the most significant U.S. Ports
(Source: Environmental and Energy Study Institute: Climate Change Mitigation and Adaptation at U.S. Ports, 2022)

In 2021, medium and heavy-duty vehicles in the U.S. were responsible for over 417 million metric tons of carbon dioxide equivalent (MtCO2e) emissions, as demonstrated in Figure 3. This figure represents almost an 8% increase from the previous year. Since 1990, emissions from these vehicles have risen by roughly 78%. In 2021, these medium and heavy-duty trucks accounted for more than 23% of the total greenhouse gas emissions from the transportation sector in the U.S. (Statista, 2023). To combat this, the U.S. Environmental Protection Agency introduced the Clean Trucks Plan in 2021 - a series of rules to reduce greenhouse gas emissions and air pollution from heavy-duty trucks.

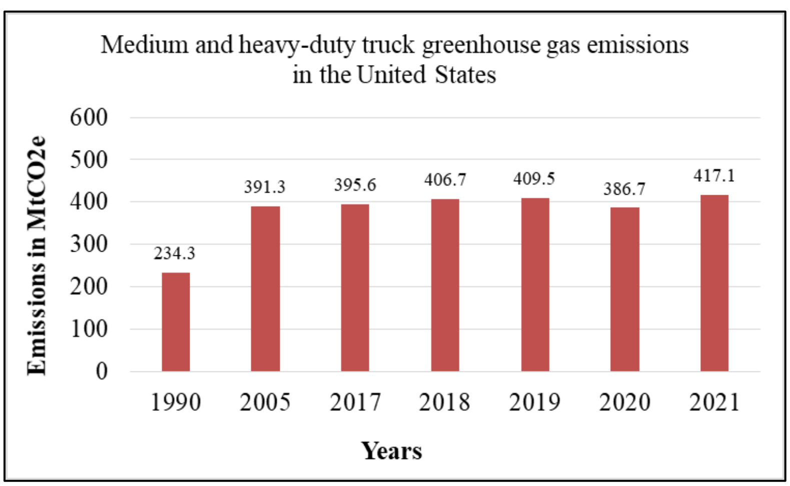

Figure 3: Medium and heavy-duty truck greenhouse gas emissions in the United States
(Source: Statista, 2023)

Besides climate-related concerns tied to greenhouse gas emissions from freight transportation, local air pollution, specifically emissions of nitrogen oxides and particulate matter, adversely affects health and the overall quality of life. These detrimental effects are most pronounced in regions near high-density freight activities. The communities living close to these freight centers and corridors, frequently populated by lower-income residents, bear a disproportionate share of these environmental burdens. (Moultak et al., 2017).

The concept of equity in transportation and accessibility outcomes can be evaluated on multiple dimensions, including horizontal equity, vertical equity, social equity, territorial or spatial equity, and generational equity. Horizontal equity refers to the degree to which individuals in the same category (income, gender, ability, and race) are regarded equally. In contrast, vertical equity refers to the equal treatment of members of distinct classes. Social equity refers to how impacts are spread among different population groups with varying needs and capacities, including income, social status, age, and mobility. Spatial equity refers to the geographic distribution of impacts, such as by region or city. Within the paradigm of social equity, there is a consensus that everyone should have at least a fundamental level of access, even if it requires additional resources and subsidies for people with special needs. This access ensures they can access essential societal services and goods like emergency help, healthcare, education, work, food, and clothes (Geurs et al., 2016). As of 2021, the trucking business in the United States supported many employments, accounting for 2,094,700 positions. These positions include drivers, mechanics, supervisors, and workers, which are required to keep the industry functioning smoothly. Approximately 3.5 million of these people are truck drivers, accounting for 61.4% of the total trucking workforce. The vast majority of these drivers, approximately 91%, work full-time, with only about 10% working part-time (McCain, 2023). The ethnic and racial demographics of the truck driving workforce in the United States are diverse, contributing to the industry's distinctive mix of people, as shown in Figure 4.

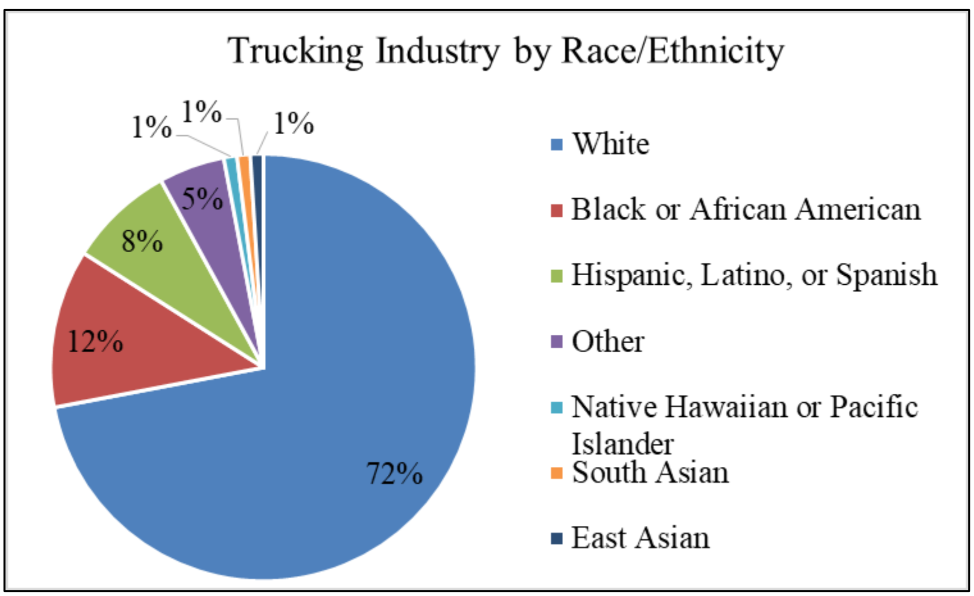

Figure 4: The ethnic/racial demographic breakdown of the U.S. truck-driving workforce
(Source: United States Census Bureau, 2021)

The USDOT prioritizes the reduction of disparities across transportation systems and the communities they serve. Equity establishment is not only about mitigating racial injustice and fostering supportive protocols for historically disadvantaged populations; it also involves sustaining a worker-friendly atmosphere (FY 2022-26 U.S.DOT Strategic Plan, 2022). Port truck drivers bear the adverse effects of port congestion and consistently report long wait times and inadequate pay. Several harbor truckers have reported idling for hours outside ports, with some even witnessing lines as long as five miles and enduring wait times of up to eight hours to access terminals in Southern California (Kay, 2021). Also, this congestion affects port efficiency, creates environmental issues due to idling trucks, and negatively impacts truck drivers' income as they are often paid per load, not hourly. Further, it disrupts local communities and risks the port's competitive edge by raising operational costs. The interdependence of these problems highlights the need for comprehensive strategies addressing environmental, social, and operational aspects of port and heavy vehicle operations (Kay, 2021).

1.2 Heavy Truck Operation Challenges

U.S. ports serve as vital engines of the national economy, functioning as crucial nodes in the global supply chain. On the other hand, truck operation is critical to port operations, whose efficiency directly influences port productivity and overall economic performance. However, high transportation costs and increased times can increase operational expenses for wholesale organizations, indirectly affecting the economy through increased inventory costs and opportunity losses. Moreover, long queues of trucks at terminal gates can significantly add to emissions, noise, and traffic jams in and around ports (EPA, 2022). The lack of sufficient truck parking areas further complicates matters, necessitating additional trips between the port and supplementary truck service areas, increasing greenhouse gas (GHG) emissions (Yıldırım et al., 2022).

The population is currently concerned about global warming, and greenhouse gas (GHG) emissions are a major contributor. Heavy-duty trucks comprise a significant part of port traffic and contribute about 40% of a port's total greenhouse gases, accounting for 3% of global carbon emissions (Fortin, 2021). Using fossil fuels to power heavy vehicles is the primary source of GHG emissions. When fossil fuels are burned, they emit a large amount of carbon dioxide (CO2) into the atmosphere. The average freight truck in the United States emits 161.8 grams of CO2 per ton-mile. Each year, over 10,000 heavy-duty diesel trucks operate in the ports, making them the region's primary source of diesel emissions (Lattanzio, 2023). The California Air Resources Board has conducted studies that have linked port-related diesel emissions to increased cancer risks for nearby residents. Furthermore, heavy-duty truck pollution contributes to poor air quality and health nationwide, particularly in overburdened and underserved communities (Alternative Fuels Data Center: Largest U.S. Port Complex Embraces LNG for Heavy-Duty Trucks, 2012).

The U.S. Department of Transportation has identified that this story intersects with the equity narrative in transportation systems. In this context, equity endeavors to reduce disparities between transportation systems and the communities they serve by promoting safe, affordable, accessible, and multimodal access to opportunities and services. The problem of ensuring equity within port facilities is becoming a pressing concern, comprising not only the mitigation of racial injustice and the support of historically disadvantaged populations but also the establishment of an employee-friendly work environment (FY 2022-26 U.S.DOT Strategic Plan, 2022).

In the context of port operations, long lines and delays for loading and unloading can increase fatigue risk for heavy truck drivers if it extends their working hours or limits their opportunities for rest. (McCartt et al., 2008). Port drivers pay the price for overcrowded ports, with long wait times and low pay regularly. They have been waiting for hours outside ports, and drivers who regularly pick up loads from ports have reported lines as long as five/six miles long and wait times of up to eight hours. This issue is further exacerbated by compensating port truckers per trip rather than hourly, diminishing their earnings due to the long wait times outside port gates. The situation is compounded when drivers face extended waits to deliver loads to inland warehouses, where personnel needs to prepare to unload their trucks. This "detention time," which is mainly unpaid, counts towards the maximum number of hours they can drive per day, further reducing drivers' earnings (Frittelli & Wong, 2021).

Because of expanding containerization and trade demand, port cargo traffic has increased dramatically in recent years. Despite the growth of intermodal and rail freight transport, road freight remains the dominant mode of transport at many ports. The road network connects ports to the hinterlands, and as port throughput increases, so does truck traffic on the linked highways (Yıldırım, 2023). The increase in truck traffic has several adverse effects, including traffic congestion, increased road accidents in areas where the port and city intersect, and increased air pollution levels (Moszyk et al., 2021). Congestion in ports is one of the most significant indicators of port performance and a critical issue that impacts seaports' productivity, efficiency, and effectiveness. A comprehensive analysis of the most influential factors affecting port congestion assists the economic and social development of the ports (Bolat et al., 2020). Congestion in the trucking industry affects terminals, transporters, and the entire supply chain. Lengthening truck turnaround or service periods is one of the most apparent consequences of congestion. Other consequences include increased fuel consumption, time losses, decreased earnings for transport operators, and increased greenhouse gas emissions. Congestion disrupts the supply chain and contributes to higher inventory, warehousing, transportation costs, and negative environmental impacts (Neagoe et al., 2021).

Given these challenges, managing truck movements is a crucial strategy to alleviate road network congestion. With ever-increasing traffic and road infrastructure, parking management is one of the significant transportation concerns. The prohibition of parking activities near the port premises causes additional operating delays, exacerbating port congestion (Raju et al., 2022). Consequently, it is essential to assess the functionality of the parking terminal across varied supply-demand scenarios. This allows for more accurate quantification of the terminal's operational performance, further informing strategies to optimize efficiency and mitigate challenges associated with port operations.

1.3 Research Objectives

The increased heavy truck movement around the port creates bottlenecks, leading to increased congestion, long queues outside the terminal gate, and a lack of available truck parking areas, further worsening the situation. Currently, various technologies and strategies aim to improve port efficiency in general and heavy truck movement, such as truck automation, truck electrification, and truck platooning systems. So, the study proposes guidelines considering the environmental impact of heavy truck operation for the community living near the port and truck driver satisfaction.

The goal of this thesis is to develop a concept of operations (coops) system to enhance heavy truck movement efficiency outside port facilities to reduce congestion and bottlenecks, lower greenhouse gas (GHG) emissions, and address equity issues for truck drivers. As a result, the current study proposes an operational concept system focusing on intermodal freight road networks, local and regional trucking companies, and the intermodal terminals they interact with to reduce transportation times, lower GHG emissions, ensure truck driver equity and incorporate with the existing freight planning system. Principally, the operation concept is examined by effectively evaluating a traffic impact study outside the Port of Miami (Case Study), identifying problems, exploring strategies to improve freight mobility, and resolving them by implementing a few ideas generated in the proposed concept without deteriorating overall network traffic conditions. This research aims to offer decision-making support to government officials, logistics service providers, and other pertinent decision-makers for sustainable and efficient intermodal freight planning. A series of steps are taken to solve the proposed problem:

Firstly, an extensive literature review is carried out on subjects related to urban freight logistics and intermodal heavy truck operation. This helps understand the current operational situation and analyze various concepts and solution techniques associated with port heavy truck operations.

Then, a theoretical foundation of the concept of operation is developed. Then, the proposed solution's effectiveness is evaluated using traffic impact analysis with an advanced simulation for the proposed case study in Florida. Later, a simulation model is developed using the PTV VISSIM Microsimulation Platform, and various experimental scenarios are simulated with different assumptions to demonstrate the model's effectiveness.

Finally, conclusions are drawn from implementing the proposed method, and recommendations for future research are made.

1.4 Research Organization

The present research study has been organized based on the following chapters: Chapter 1 provides a broad introduction to the research topic, including heavy truck operation around port areas, greenhouse gas emissions from heavy truck movement, and equity issues faced by truck drivers and people living around the port community. In the following chapter (Chapter 2), a comprehensive literature review is conducted to identify existing studies associated with the concept of operation, traffic impact assessment, and heavy truck operation systems near port areas, as well as proposed solutions for the truck bottleneck problem outside port terminal gates.

The overview of the problem, the development of the operation concept, and the proposed solution diagram are described in Chapter 3. Chapter 4 develops the methodology for conducting a traffic impact study, including different experimental scenarios to evaluate the model's effectiveness. Chapter 5 presents and discusses the results and comparative analysis of various simulation scenarios. Finally, Chapter 6 discusses the research findings and provides recommendations for potential future studies.

2. Concept for Proposed System

2.1 Background, Objectives, and Scope

Heavy truck traffic flow outside intermodal facilities such as ports is a vital component of the supply chain system. However, inefficiencies in the current system are causing delays and negative environmental impacts. To address these issues, a concept of operation can be developed that can be helpful for the United States Port outside truck operation to prioritize a flexible and responsive technology program involving both public and private-sector collaboration. This system provides an overview of how the system will function without going into specific technical details or solutions. It provides a structure for decision-making and communication among the stakeholders and serves as a guide for developing more detailed plans and procedures. The primary goal is to increase the efficiency of heavy truck traffic flow outside of intermodal facilities. This can be achieved by reducing the waiting time for trucks to minimize the environmental impact. The secondary objective is to mitigate equity concerns by ensuring equal access to resources and opportunities for all involved personnel.

To achieve the objectives, the following approach can be taken:

Smart Queuing System and appointment system: A smart queuing system can be implemented to optimize the heavy truck operation outside the port terminal gate, and this system can utilize real-time reliable data sources to predict the arrival time of the trucks and prioritize them based on their waiting time and route planning to reduce congestion and wait times. In addition, a truck appointment or scheduling system can be implemented to control the traffic of trucks entering the facility during peak hours. This system would enable trucking companies to reserve specific time slots for their trucks to enter and exit the terminal gate.

Use of Technology: Utilizing technology can be an excellent method to improve the efficiency of heavy truck operations. Intelligent transportation systems, such as real-time reliable traffic monitoring systems and communication technologies with the truck drivers and operational managers, can optimize truck traffic and help reduce trucks idling time outside the terminal, thereby reducing emissions and fuel consumption. To reduce the environmental impact of heavy truck traffic, the use of alternative fuels and technologies such as automated, electric, and hybrid vehicles can be encouraged. To encourage trucking companies to implement these technologies, incentives must be taken.

Infrastructure Development and Collaborative Efforts: Infrastructure development, including new truck parking areas such as overnight truck stops and rest areas, can be prioritized to provide drivers with safe and secure resting areas. This will reduce the waiting time and increase the heavy truck operation's overall efficacy. In addition, stakeholders, including trucking companies, port authorities, and other public and private agencies involved in the supply chain, will be encouraged to collaborate. This will result in more coordinated and efficient operations.

This system mainly focuses on three primary user groups. For example, dispatchers and operations managers of a trucking company are responsible for route planning and communication with truck drivers. Moreover, truck drivers are responsible for picking up and delivering containers to a particular location. Long wait periods outside the port terminal's gates have a significant negative impact on truck drivers. Additionally, the population residing near the port area is exposed to environmental and noise pollution due to extreme truck congestion. Regarding these three primary user groups, the proposed concept focuses primarily on the intermodal road network, drivers, and the intermodal terminals they interface with. Principally, the concept of operation is observed by identifying problems and resolving them using the concept, and two primary groups of concept functional areas can be identified based on user effort requirements and potential functionality:

Implementing Dedicated Separate Truck Lane: The goal is to address the topic of implementing special truck treatments on the road, develop a truck road network, and make recommendations for implementing a pilot system. Trucks can utilize only specific lanes that are designated only for their use. Sometimes no other vehicles are allowed to use the exclusive lane just to reduce the car-truck interaction. These exclusive lanes can be physically separated from other lanes, or sometimes other vehicles can access those lanes (Middleton et al., 2006).

Automated Truck Platooning: The goal is to address the Automated Truck Platoons (ATP) on a typical freeway near the port area and determine the enhancement it provides for reducing roadway traffic. Trucks can be completely automated or partially automated. Also, multiple trucks can be connected based on requirements or freight carried by trucks. The truck platoon has the right to choose specific lanes, and they can travel through the highways. However, they can get separated whenever they travel through any intersection, and after passing the intersection, they can choose their specific route (Sharifiilierdy, 2021).

2.2 Description of CONOPS Essential Features, Capabilities, and Functions

This section describes the proposed concept system due to the previously discussed objectives and user requirements. A medium-level description of the proposed system is provided, considering the operational capabilities that will be described without elaborating on design details or technological solutions. This section describes multiple scenarios in which the proposed concept could substantially improve transportation and freight operations. The scenarios will describe how the system interacts, but they are solely examples where specific technologies are mentioned; they should not be interpreted as a technological solution.

2.2.1 Scheduled appointments, truck parking availability and location, etc. around port terminal regions.

Appointment scheduling and parking availability refer to some of the operational aspects around a port terminal or an intermodal facility. A brief overview of each topic is described below:

2.2.1.1 Scheduled Appointments:

The first step would be applying specific schedule appointments for the arrival and departure of trucks at the terminal gate. This will help reduce congestion, queuing and waiting times as the trucks will be given specific time slots to pick up or drop off cargo, and any delays or changes will be communicated with the truck drivers.

2.2.1.2 Truck Parking Availability:

To reduce the time that truck drivers spend waiting for cargo to be loaded or unloaded, there should be adequate parking spaces available near the port terminal regions. This will prohibit trucks from illegally parking in residential areas or blocking traffic while waiting for cargo loading. The parking lots should be conveniently positioned and easily accessible, with amenities such as restrooms, overnight resting areas, showers, food, and fuel stations. Truck drivers traveling a short distance may proceed directly to their allocated terminal gates. Before approaching the port area, the truck driver should get truck parking availability or location information, and drivers driving short distances can park at nearby spots, called short-time resting areas. So, there should be two distinct truck parking options available; one is designated for truck stops, while the other is for a short time rest area. Short-distance drivers can park for one to two hours in the rest area. In addition, the truck stop serves drivers traveling long distances. Some truck drivers travel for up to two days to reach the port terminal. They may go to the authorized truck stop area and park their vehicle for as long as they desire before proceeding to the terminal gate (Chatterjee & Wegmann, 2000). This parking availability and location information should be conveyed to truck drivers before their appointment so that they do not have to wait for an extended period outside the terminal gate and park their vehicles in a residential neighborhood or on the roadside.

2.2.1.3 Technology Integration:

To increase efficiency, technology can be integrated into the trucking system. This involves integrating GPS tracking systems to monitor and optimize truck routes, using automated cargo handling systems such as loading and unloading of the freight and delivering real-time traffic information and parking availability location to the truck drivers. Another important implication is smart traffic management technologies that can be useful to improve traffic flow and minimize congestion. This includes using intelligent traffic signals systems in the arterial roads that modify their timing based on traffic volume, and real-time traffic monitoring during peak hours.

In this instance, both truck drivers and residents of the port community can benefit because when trucks wait outside the gate, they remain idle and continue to emit greenhouse gases into the atmosphere. As a result, rest areas for truck drivers should remain open during emergencies such as road closures or overnight parking situations, especially for trucks traveling from long distances. Also, drivers' security and safety should be a shared concern, and industry stakeholder coordination and public-private collaboration opportunities are required to address capacity needs.

2.2.2 Reliable real-time information regarding major roadways, freeways, arterials, etc., outside port terminal regions

Reliable real-time information on road conditions, traffic movement, and potential disruptions is essential for effective freight movement, particularly outside port terminal locations. This data assists logistics operators, drivers, and dispatchers in making well-informed choices and adjust routes or schedules as needed to avoid delays and enhance efficiency. Some ways this information can be provided include:

2.2.2.1 Real-time information system:

A real-time, reliable information system should offer truck drivers and fleet managers information on current traffic conditions, congestion levels, and alternate accessible routes. This system may collect data and update traffic conditions in real-time using multiple technologies such as GPS, sensors, traffic cameras, and traffic monitoring systems. The idea is to provide real-time information on freeways, port, and terminal intermodal connectors, and important freight arterials.

2.2.2.2 Intelligent route planning:

With the help of real-time data, an intelligent route planning system can be developed to determine the most efficient route for trucks based on traffic, road conditions, and other factors. The system may also calculate the load capacity of the trucks and recommend the most efficient routes. This data will include traffic volumes (trucks and cars), vehicle speeds from regionally available ITS data, point-to-point travel time predictive information (freeways and arterials), incident information (clearance estimation, construction and work zone information, and so on), and should be deployed during the concept's development phase.

2.2.2.3 Technology-enabled communication:

Technology-enabled communication systems such as Smartphones, tablets, and in-cab devices can be used to keep drivers informed and facilitate real-time communication with dispatchers and other drivers. This can help to improve the efficiency of the overall transportation network by reducing idle time and improving scheduling. All the information should be displayed through the mobile application to the truck drivers and dispatchers and provide audible alerts for truck drivers.

2.2.3 Implementation of freeway lane restrictions, dedicated or exclusive truck lanes, and truck roadways.

Implementing freeway lane restrictions, dedicating lanes exclusively for trucks, or establishing truck roadways can significantly benefit freight transportation. Such strategies can enhance traffic flow, improve safety, and lead to more predictable delivery times. Here are some details about these measures:

2.2.3.1 Dedicated truck lanes:

On the freeway, a dedicated truck lane system can be implemented; these lanes are not separated from the main lanes by barriers, and other vehicles are prohibited from using them. This system will enable heavy trucks to move quickly without being interrupted or delayed by other vehicles on the road. This will reduce the time trucks take to reach their destinations, thus improving the efficiency of truck traffic flow.

2.2.3.2 Exclusive truck lanes:

Exclusive truck lanes will be significantly more effective in decreasing congestion because they will be dedicated entirely to trucks and will not be accessible to other vehicles. Trucks use a facility that is specifically designed for their use. These lanes are frequently separated from the non-truck lanes by barriers or medians. This would reduce the potential for accidents, often caused by cars and smaller vehicles driving too close to large trucks.

2.2.3.3 Freeway lane restrictions:

Another way to improve heavy truck traffic flow efficiency is to introduce lane restrictions during peak hours. This would involve restricting the number of lanes available for regular traffic and reserving more lanes for heavy trucks. This would prevent the heavy trucks from getting stuck in traffic jams caused by other vehicles, thereby improving their movement and reducing congestion.

The potential benefits of truck-only lanes for a trucking company include reducing the risk of car-truck collisions and economic benefits for the trucking industry. If trucks occupied lanes with less traffic, they could operate more efficiently. Less frequent braking, acceleration, and passing would lower operating costs per mile. The increased capacity would assist in relieving congestion, thereby reducing travel time and arrival time uncertainty. Additionally, truck-only lanes would enhance the speeds of passenger vehicles. Since the acceleration and braking performance of trucks is significantly inferior to that of most passenger vehicles, removing trucks from heavy traffic segments could considerably improve traffic flow (Forkenbrock and March, 2005).

2.2.4 Vehicle-to-vehicle communication by implementing Autonomous Truck Platooning in the freeway.

Autonomous Truck Platooning (ATP) is an emerging technology that leverages vehicle-to-vehicle (V2V) communication and autonomous driving systems to enable trucks to travel in closely spaced convoys or "platoons" on freeways and other major roads. Here's how it works:

2.2.4.1 Designation of Platooning Zones:

Automated Truck Platoons (ATP) enable a group of commercial trucks to travel faster and with a closer distance between them while maintaining safety. Through assisting drivers and reducing human error, ATP is anticipated to increase traffic safety (Olia et al., 2018). These truck platoons automatically maintain a predetermined, close spacing between each other while connected for particular periods of a journey, such as on highways. The platoon leader is the truck at the front of the platoon, with the vehicles following it, reacting and adapting to its path with minimal driver intervention. In the first instance, drivers will always retain control, allowing them to leave the platoon and drive independently (Spasovic & Lee, 2019). The first step would be to designate specific areas on the road or near the port area for platoon formation. Traffic flow patterns and distance from port facilities should determine these zones.

2.2.4.2 Truck Fleet Selection:

The next step would be Identifying and selecting a fleet of trucks equipped with the essential Autonomous Vehicle (AV) technology for platooning. These trucks should be able to communicate with each other through Vehicle-to-Vehicle (V2V) communication technology. These platoon vehicles can be operated manually or semi-automatically. Truck platoons can occasionally use the intersection and split as they pass the intersection before reforming. The leader is responsible for communicating with infrastructure to obtain permission to cross intersections. But it is challenging to use vehicle platoons in residential areas because of high congestion, so the trucks may form platoons or pass as single vehicles depending on the volume of traffic in the residential area. A centralized control system would be established to manage the platooning operations, which will monitor the platooning trucks, collect data, and provide real-time information. The platooning process would be initiated after identifying the platooning zones and selecting the vehicles. The first vehicle in the platoon would be piloted by a human driver who would serve as a platoon leader. The following trucks would be driven autonomously, with the drivers monitoring the platooning procedure from within the cabin.

In previous and ongoing Federal Highway Administration (FHWA) research works, the trucks are partially automated, meaning that the vehicles control the coordinated speeds and braking with the lead vehicles in the platoons. Still, the drivers retain steering control at all times.

Drivers are expected to constantly monitor road conditions and be ready to assume complete control of the vehicles at any time. It adds vehicle-to-vehicle communications to enable cooperative adaptive cruise control (CACC) and demonstrates connected vehicle technology for enhanced stability and responsiveness of truck platooning operations. Significant national economic advantages will result from widespread deployment, including potential reductions in driver workload and enhanced driving comfort (Truck Platooning | FHWA, 2021).

2.3 User Class Profiles and Other Involved Personnel

This section describes the proposed system's User Classes. These User Classes are identical to those previously described. This information is replicated here for completeness and traceability. The principal user groups for the proposed system are categorized as follows:
Trucking Company and Operations Managers are responsible for trip planning and communicating with truck drivers. Trucking companies own or operate the trucks that transport goods from the port intermodal facilities. To optimize the use of their trucks and reduce waiting times, they will require real-time information such as traffic conditions, parking availability (stop and rest area), and appointment scheduling. The individuals who supervise the daily operations of the trucking company are known as operation managers. They will need information from terminal operators, shippers or receivers, cargo handling authorities, other carriers, and truck parking authorities (Jensen et al. 2012). They will use this information to decide on route planning, scheduling, and truck dispatching. They will communicate with the drivers through cell phones, SMS texts, and mobile computing platforms. Also, they could utilize a centralized digital platform that enables communication and coordination in real-time. The platform could provide access to digital maps with traffic data, such as Google Maps, information from traffic cameras, weather reports, accident reports, information about construction and work zones, and other resources.

Truck drivers play an essential role in the logistics industry's transportation of products and materials. They collect and deliver containers while adhering to the truck schedule system. Efficient communication between truck drivers, dispatcher companies, and operation managers is essential to ensure that truck drivers receive accurate information regarding appointments, parking availability and location, entry and exit times, container availability, and the location of the terminals. In addition, truck drivers should have adequate knowledge of the truck route system on freeways and arterials, including information on designated truck routes or truck-exclusive lanes during peak hours or normal hours, their specific locations, and any other pertinent information. Those responsible for operating the Automated Truck Platoon should thoroughly understand the system's requirements, including the duration of travel with the platoon system, the available freeway segments, the specific headway to maintain, and the correct procedure for following the truck leaders. Effective communication tools, such as radios and cell phones, are essential for truck drivers to communicate with other drivers and dispatchers. Moreover, the driver may contain a computer system that provides GPS-based route instructions, facilitating their ability to carry out their responsibilities effectively. In addition to appropriate communication, factors such as fatigue, distractions, and health issues can affect the performance and safety of truck drivers. Promoting healthy practices, providing suitable training and support, and implementing effective safety measures are essential to mitigate these risks.

The involvement of other personnel, such as residents living nearby ports, both public and private sector persons, are essential in the success of the proposed solution to reduce greenhouse gas emissions of heavy-duty vehicles. Although these people are not directly involved in the system, they stand to benefit from it. Implementing a dedicated or exclusive truck lane can reduce environmental pollution, road congestion or bottlenecks, and car-truck interactions, thereby reducing the number of car-truck collisions. The use of truck platoons on the road can also have a positive effect on the environment and traffic flow. In addition, the operations personnel at state DOTs (Department of Transportation), regional MPOs (Metropolitan Planning Organizations), and TMCs (Transportation Management Centers) can play a crucial role in managing traffic operations and facilitating daily operations planning for truck drivers and dispatchers/operations managers. These entities can provide valuable resources and information, such as real-time traffic updates and route planning tools, to facilitate the efficient and secure transportation of products and freight.

2.4 System-Level Operational Processes

This section provides a conceptual overview of the proposed system's processes, built on the information provided in the preceding sections, such as proposed concept functions, user class profile, involved person, and aim or objectives of the situation. Figure 5 illustrates the key relationships and connections within the concept and provides a conceptual representation of the proposed system, incorporating Freight-Specific Dynamic Travel Planning developed by USDOT. Because the USDOT has developed a travel planning system, the suggested system concept, such as constructing a truck stop and rest area, a dedicated truck lane, and a truck platooning system, can be incorporated into the travel planning system (Freight-Specific Dynamic Travel Planning, 2022).

The system's foundation can be constructed as a primary application package to be incorporated into any existing public sector computer application systems connected within a port community region. Transportation authorities in both the public and private sectors will take the initiative and be in charge of the system installation process, preparing the website and smartphone app, overall maintenance, and managing the system operation, and ensuring smooth integration and effective operation. Trucking operation managers can access the suggested system or the application package via the website and truck drivers via a smartphone app or an audible mode. As discussed earlier, the Freight-Specific Dynamic Travel Planning system prepared by USDOT can help the proposed system. The operational concept system will be linked with the Freight-Specific Dynamic Travel Planning because it can assist in obtaining real-time information, incident management data such as lane closure, construction zone and work zone information, and coordination of heavy vehicle traffic movements. The operational concept diagram is a complete system diagram that contains the following fundamental elements:

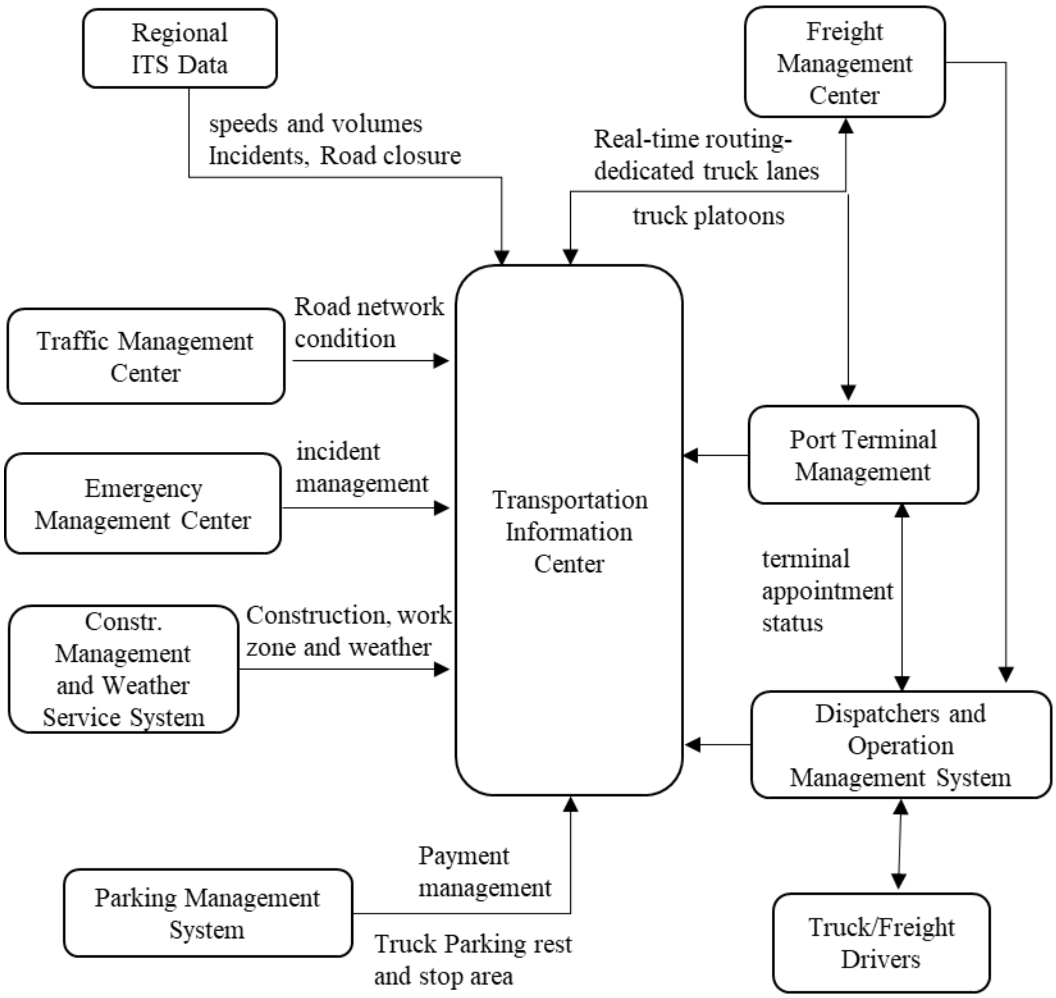

Figure 5: Proposed System Concept

First of all, Major metropolitan areas in the United States can help implement the system because they typically have access to numerous sources of real-time traffic information and ITS data, such as freeway/arterial speeds and volumes, incidents, road closures, parking locations, and physical/regulatory restrictions, etc. (Simmons, 2006). For effective use of these data sources, coordination and collaboration between public and private sectors, such as MPOs, DOTs, RITIS (Regional Integrated Transportation Information System), etc., is necessary.

Transportation Information Center (TIC) can be beneficial in this regard. The center is essential in collecting, processing, storing, and making transportation data available to system operators and travelers. It transfers collected data to other regional system operators, ensuring that traveler information is delivered correctly to the general public. Furthermore, the center collects real-time vehicle routing decisions to determine the truck-restricted lane availability and establishes relationships with operation managers. Moreover, the system addresses traffic flow on arterial roads, with most major metropolitan cities incorporating some form of integrated signal control system to enhance traffic flow throughout their roadway networks (Transportation Information Center, 2023). According to USDOT Freight-Specific Dynamic Travel Planning

System, TIC is typically implemented as a website or web-based application service. So, our suggested system can be incorporated with this system. However, it can also represent any traveler information distribution service. Among the Management Centers from which data is collected are:

The Traffic Management Center can provide information to the TIC because it supervises most CCTV cameras and ensures proper traffic supervision and regulation of the overall road system. This facility manages many transportation facilities, such as freight vehicle traffic control systems on freeways and arterial roads. The center successfully manages traffic flow while monitoring roadway conditions, the surrounding environment, and the status of field equipment by engaging in effective communication with ITS Roadway Equipment vehicle information and Connected Vehicle data (Smith, 2005). The center can supply vehicle volume to the TIC for a variety of peak-hour situations and also collaborates with port authorities to promote a simpler freight planning system.

Emergency Management Center: This center supports ITS applications focused on security and public safety, incident management, efficient disaster response, and evacuation system, security monitoring, and other interconnected functions (State Operations Center SOC - Emergency Management Center Functionality, n.d.).

Construction Management and Weather Service System: They expertly manage the development and maintenance of transportation infrastructure for both public and private contractors. Beyond the port area, they collect important weather data and information on construction and work zone operations affecting the road network. This includes the location, anticipated timeframe, duration, summaries of anticipated delays, alternate route options, and estimated speed limits. Further assist truck drivers, visual aids displaying the current work zone status are provided, enabling them to identify alternate routes and allowing truck platoon commanders to avoid work zones (Osborne et al., 2005).

Truck Parking Management: This system is responsible for parking facility administration, including the configuration and management of field infrastructure, the maintenance of user accounts, and the incorporation of financial systems for payment processing. The proposed system provides essential parking information, including location, availability, and pricing. It also collaborates with the freight management center to assist users in locating appropriate truck parking options, thereby reducing the likelihood of long lines and parking on the side of the road. In addition, truck drivers will have real-time access to truck stop and rest area information, essential for making more informed decisions (Texas Truck Parking Management System, 2021).

Freight Management Center: The center is a valuable resource for commercial drivers and fleet-freight management, providing real-time route data and comprehensive databases comprising information on vehicle and freight equipment locations, carriers, vehicles, and drivers. This enables the center to assist truck drivers in selecting optimal routes. The critical function includes monitoring the terminal, truck appointment, and container availability, providing delivery and booking status updates to freight vehicle drivers, providing real-time location details of exclusive or dedicated truck lanes, informing operation managers of the availability of exclusive lanes for truck drivers or shared usage with passenger vehicles, compiling truck platoon data, and integrating freight traveler information into the broader transportation system (Fleet and Freight Management Center, 2023).

3. Methodology

2.5 Overview

In this chapter, the methodology is presented, and the main focus of the methodology is to conduct a traffic impact study by incorporating specific research ideas from the developed concept of operation as described in the previous chapter. The methodology's first part discusses the case study area chosen for the traffic impact study, implementation of strategies, their effects evaluation on traffic networks, data collection, development of microsimulation model, and calibration of the model using PTV VISSIM (2023). The second part of the methodology involves preparing guidelines related to the simulation network, model development, evaluating various scenarios, and forecasting the model with increased truck volumes.

The study's objective is to conduct a traffic impact study, enhance current freight mobility and prevent worsening traffic congestion in the overall network. After implementing the suggested strategies, this objective is intended to be achieved. The process for effectively developing the study's methodology begins with a detailed explanation of the problem. Next, the method used to solve the problem and the resulting outcomes are analyzed. At first, a case study area is selected, and required data, such as vehicle volume, speed distribution, vehicle classes, etc., are collected to develop the simulation model network.

Following data collection, the microsimulation platform VISSIM is used to create the base network, and the model is calibrated by modifying the model's default parameters. The model then develops seven distinct strategies, including dedicated truck lanes, truck platoons, vehicle platoons, etc. Then, for current traffic conditions such as AM Peak Hour (7-9 AM), Normal Hour (12-2 PM), and PM Peak Hour (4-6 PM), each scenario model is developed and run for ten replications with a random seed increment. Each model is executed for traffic forecasting scenarios with 10% increased truck volumes. Traffic forecasting entails anticipating future traffic conditions based on current and historical data. According to the literature, traffic volume is predicted to increase yearly, and the study intends to analyze the operational movement of truck flow. So, because this study includes adding methods such as dedicated truck lanes and truck platoons, we are making assumptions about increased truck numbers for our simulation network and seeing how they behave in the simulation network compared to present traffic conditions. After that, the vehicle travel time and delay results for each scenario are compared. The detailed Flowchart of the developed methodology is described in Figure 6 below:

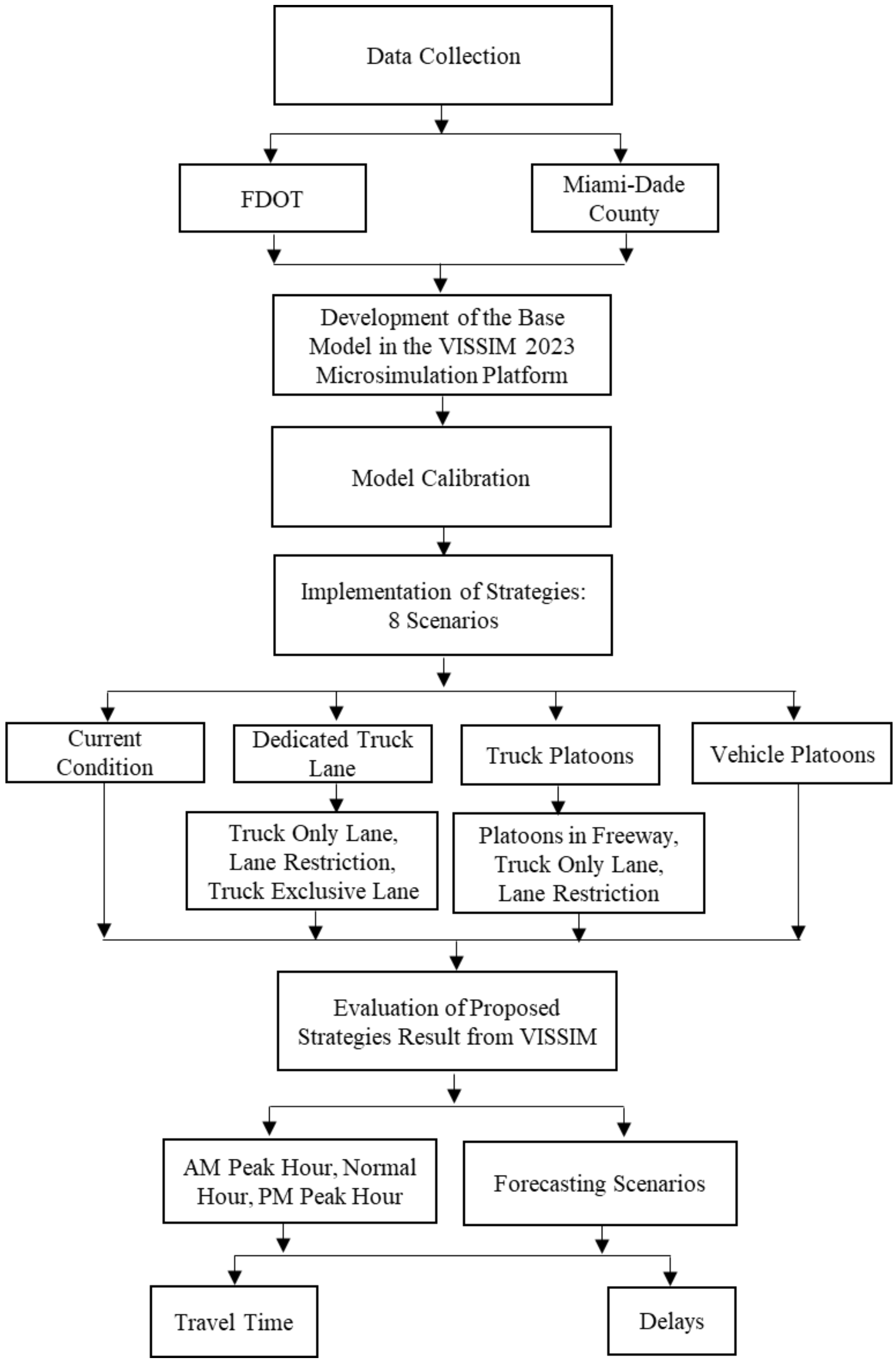

Figure 6: Methodology Flow Chart

2.6 Case Study

Implementing traffic management strategies simultaneously aims to alleviate congestion resulting from truck traffic. In order to assess the effectiveness of these methods, a case study should be conducted in an area with significant congestion, accommodating increased volumes of both trucks and motor vehicles. In Florida, certain regions experience heightened congestion levels in proximity to freight facilities, particularly near ports. Miami-Dade County, one of the busiest areas in Southeast Florida, includes the Port of Miami, Miami Tunnel, and Biscayne Boulevard. Figure 7 shows the geographic locations of Miami-Dade County in the state of Florida. The Florida Department of Transportation (FDOT) provided various Geographic Information System (GIS) maps, which were used to reach this conclusion. The maps depicted the percentage of freight presence and corridor sections in each Florida county. By comparing these maps, Miami-Dade County was selected for further investigation, with a focus on the Port of Miami area and the observed percentage of freight movements.

The Port of Miami is a major seaport in Miami, Florida, located in Biscayne Bay at the mouth of the Miami River. Figure 8 shows the location Port of Miami within the State of Florida. It is the largest passenger port in the world and one of the busiest cargo ports in the United States (Ahmed, 2022). Traffic issues near the ports seem to be influenced by the growing number of trucks responsible for transporting cargo to and from western Florida's port and distribution centers. This study examined areas outside the port area such as the highway and arterial roads, including the Port of Miami Tunnel, which links the port to the MacArthur Causeway. The Miami Cruise Port is connected to Miami International Airport via the Dolphin Expressway. The entrance to the Port of Miami is located at Biscayne Boulevard and Port Boulevard (NE 5th Street). Additionally, I-395, a brief stretch of interstate highway in downtown Miami, connects I-95 to the Port Miami tunnel and FL-A1A toward Miami Beach, as shown in Figure 8. The primary factors contributing to reduced vehicle capacity include lane reduction, interactions between trucks and cars, and collisions involving trucks and cars.

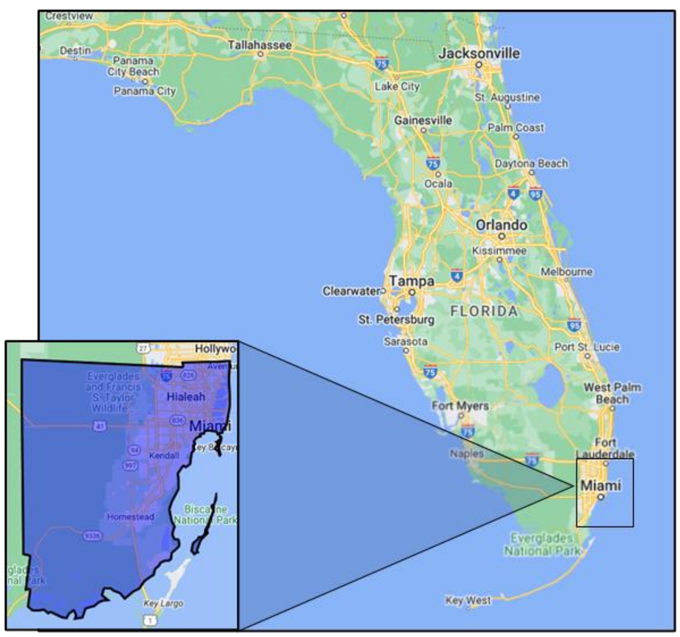

Figure 7: Location of Miami-Dade County in the State of Florida
(Source: Google Maps)

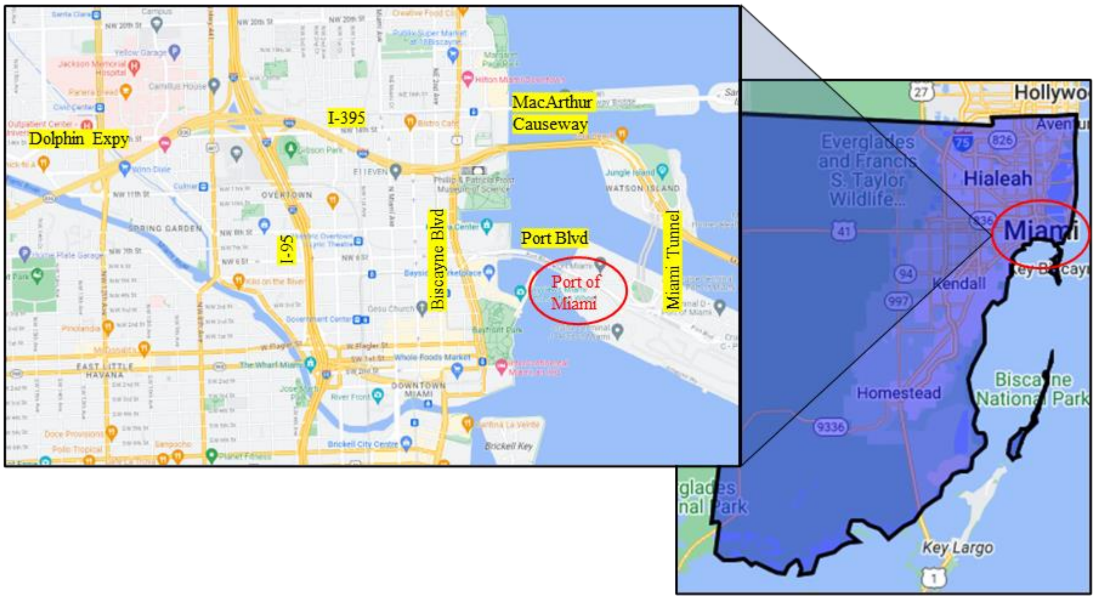

Figure 8: Geographic Location of Port of Miami
(Source: Google Maps)

2.7 Microsimulation Model

In this section, we discuss the development of the microsimulation model in PTV VISSIM, including the data used (vehicle volume, vehicle class, vehicle composition, speed, etc.), simulation features, calibration procedure, design of the base scenario, and other strategic scenarios. The testing technique and results are described in the following chapter.

2.7.1 Microsimulation Software

PTV VISSIM is a widely used multi-modal traffic flow simulation software package and it was firstly developed in 1992 by PTV Group in Germany. It is now a prominent simulation technology for optimizing the movement of people and goods (Vortisch, 2015). PTV VISSIM enables users to simulate real traffic conditions, model various geometries, and analyze traffic flow impacts. It accommodates microscopic, mesoscopic, or hybrid simulations and includes different modes of transport. This versatility allows experts to analyze different transport mode interactions, junction geometries, and the effects of varying signal patterns. PTV VISSIM is a versatile software that offers flexibility in modeling geometry, allowing users to apply different traffic patterns and road user characteristics. Additionally, the software provides the capability to interact with external applications through a generic COM interface.

2.7.2 Model Development

At the beginning of developing the microsimulation model using the simulation software, it is necessary to collect information about the specific road geometry, operational traffic system, and control systems. The operational traffic system includes data collection about traffic through volumes, turning movement volumes, individual speeds of vehicles, lane usage, individual road speed, vehicle composition, vehicle types, and signal planning sheets, and the data were collected from Miami-Dade County and FDOT (Florida Department of Transportation) Open Data Hub. FDOT Traffic data may contain daily counts, vehicle classification, speeds, weight, directional factor, truck factor, and design hour factor, depending on the location (FDOT Traffic Information, n.d.). The data relating to the vehicle movement along Dolphin Expressway, I-95, and I-395 were collected from the Website of RITIS (Regional Integrated Transportation Information System) and FDOT online Open data hub. Traffic volume counts for Miami Tunnel, Biscayne Boulevard, and Port Boulevard were obtained from Miami TMC and FDOT Open Hub Synopsis and AADT data 2021. Some assumptions were made regarding arterial traffic movement data and turning movement data. In addition, the focus of this study was on enhancing freight mobility, so every effort was made to replicate the model's freight characteristics as precisely as possible. During the calibration procedure, key variables such as vehicle speed distribution, following distance, lane change, and lateral movements were carefully analyzed and adjusted to reflect real-world traffic conditions accurately. The model also incorporated the percentage of trucks traveling along highways, residential areas, and arterial roads. These percentages vary based on road geometry and function, such as the percentage of vehicles on freeways and highways, and the study location, such as an urban or rural area. After Developing the model, eight segments from the network are selected for result analysis. Table 1 represents the segment number and directions of the road network for result evaluation.

Table 1: Road Network Segments

Segments	Directions
1	Dolphin Expy-Tunnel (EB)
2	Dolphin Expy-Tunnel (WB)
3	Port Blvd (EB)
4	Port Blvd (WB)
5	I-95-Biscayne Blvd (NB)
6	I-95-Biscayne Blvd (SB)
7	I-95-Tunnel (EB)
8	I-95-Tunnel (WB)

2.7.3 Model Calibration

Calibration is a fundamental aspect of the microsimulation model. Calibration refers to adjusting the default parameters of a computer simulation model to represent the existing real-world roadway network conditions effectively. (Wunderlich et al., 2019). Several model parameters, such as link behavior, driving behavior, vehicle routing, vehicle speed distributions, vehicle composition, vehicle type and class, and specific route speed distribution parameters, are changed in the model. In this study, some default parameters in VISSIM Microsimulation are changed, while others are used as-is, particularly in driving behavior such as driver lane-changing behavior, car-following behavior, lane change gap acceptance, vehicle acceleration distributions, etc. For freeway road segments, freeway lane driving behavior is used; urban motorized behavior is employed for residential roads. For speed distribution, maximum speed limit data from the

FDOT is used to get individual road speeds considered in the simulation model. For vehicle composition, different percentages of vehicles, such as cars and trucks, are included in different road networks. Some of the VISSIM Calibration Settings used to create the base model are displayed in Table 2 below.

Table 2: VISSIM Calibration Settings

Parameter Grouping	Parameter Name	Recommended Parameter Range
Base Settings	Vehicle Types and Class	Car, HGV, Bike Man, Bike Woman
	Functions (Maximum and Desired Acceleration/Deceleration)	Default
	Vehicle Characteristics function and distribution	Speed Distribution: left turn 12.4 to 18.6 mph; right turn 7.5 to 15.5 mph
	Speed Distribution	Tunnel: 35 mph
		Port Blvd: 40 mph
		Biscayne Blvd: 30 mph
		MacArthur Causeway: 45 mph
		I-395: 55 mph
		I-95: (55-60) mph
		Dolphin Expy: 45-55 mph
Traffic Settings	Vehicle Composition (Veh Type; Reflow)	Default: Car-0.94, HGV-0.04, Bike-0.02
		Tunnel: Car-0.623, HGV-0.378
		Biscayne Blvd: Car-0.93, HGV-0.05, Bike-0.02
		Port Blvd: Car-0.877, HGV-0.123
Car Following	Car Following for Freeway & Arterial	Wiedemann 74 Car following model (applicable for arterials)
		Wiedemann 99 Car following model (applicable for freeway/highway)
Signal Control		RBC

After completing the calibration, the model is considered ready for usage because it replicates the network's actual traffic conditions. Based on the aim of study specific users can then prepare their own scenarios and execute them in the model. And finally, the calibration procedure is completed, and the base model, which replicates current traffic conditions outside the Port of Miami area, is developed.

2.8 Development of Strategies

For the scenario development, a total of eight scenarios are prepared to run the simulation model. Based on the developed concept, this study intends to implement a few research ideas, such as implementing dedicated truck lane and platoon formation on the freeway and examine how the model scenario provides results or influences the present traffic circumstances. Table 3 below represents the total scenarios developed in the microsimulation model.

Table 3: Implementation of Strategies

Scenarios	Descriptions
1	Base Scenario
2	Truck Only Lane
3	Lane Restrictions
4	Truck Exclusive Lane
5	Truck Platoons
6	Truck Platoons-Dedicated Lane
7	Truck Platoons-Lane Restrictions
8	Vehicle Platoons

2.8.1 SCENARIO I- Base Scenario

Various scenarios are generated and implemented after successfully calibrating the simulation model using the processes mentioned above. First, a base scenario is created that replicates the network's present traffic conditions. The base scenario offers a general understanding of the road network's operation and how trucks interact with other vehicles. Furthermore, it is important to investigate the most congested places that hamper vehicle operations and determine the underlying causes. The base model is regarded as the most critical of all the models generated in the study, as it is the foundation for the development of additional scenarios. The impact analysis's effectiveness is also determined by comparing the base model with each scenario individually. Therefore, identifying the current traffic conditions through the base scenario observation is vital for analyzing the implemented scenarios' results. The model runs for two hours, and each simulation scenario runs for ten replications with different random seeds to evaluate the impacts on traffic flow based on the appropriate performance measures, average speed, total travel time, and total network delay, replicating the morning peak hour (7-9 AM), normal hour (12-2 PM), and evening peak hour (4-6 PM). After running the simulation model for ten replications, the model is run for forecasting scenarios during the AM peak hour, normal hour, and PM peak hour with increased truck volumes. Figure 9 displays the base model extracted from the PTV VISSIM software.

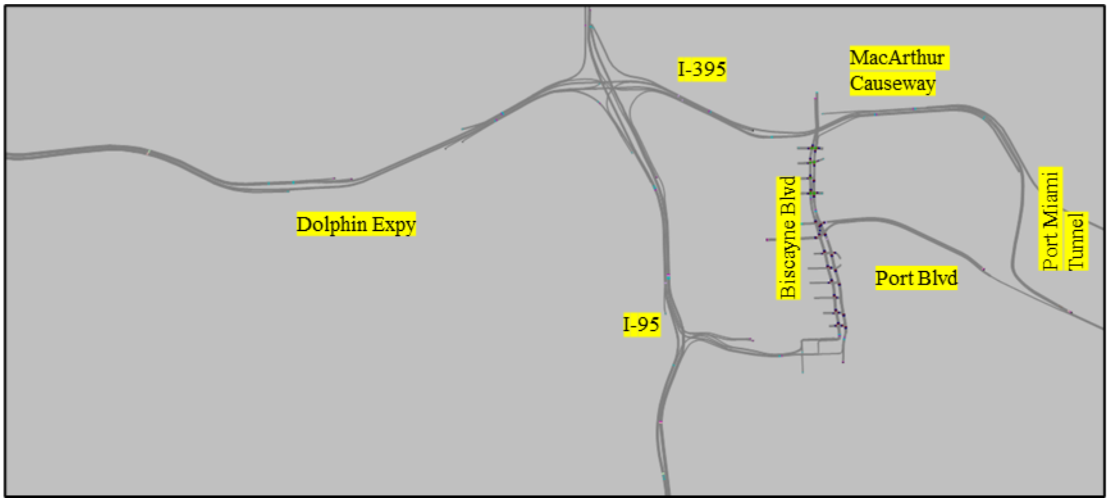

Figure 9: Base Model from the PTV VISSIM Software

2.8.2 SCENARIO II- Dedicated Truck Only Lane

Before implementing the strategies simultaneously, it is necessary to implement each separately to evaluate their impact on the road and improve traffic flow. The primary scenario revolved around the effective establishment of a dedicated truck lane strategy designed to enhance freight mobility along major routes such as the Dolphin Expressway and I-395, which are frequently used by trucks before entering the Port of Miami Tunnel. In the microsimulation model, the dedicated truck lane is applied as outlined in the proposed operational concept, with the lane designated on the left side of the road. Notably, there are no lane restrictions while taking exits. Due to the high levels of congestion typically found in the Port of Miami area, dedicated truck lanes are exclusively implemented on the freeway, avoiding residential areas. As per the FDOT Open Data Hub, it is estimated that in 2022, more than 5400 trucks traveled in both directions using the I-395 corridor before proceeding to the Port of Miami via the tunnel, as shown in Figure 10. In light of this, the introduction of a dedicated truck lane has the potential to significantly reduce interactions between trucks and cars, subsequently improving traffic flow and overall road safety. In addition to enhancing safety, dedicated truck lanes can also contribute to reducing emissions by facilitating more consistent truck speeds and minimizing stop-and-go traffic patterns typically associated with mixed traffic. The scenario is developed to prioritize freight transport and examine how a dedicated truck lane influences the efficiency of both trucks and general traffic. The model runs for two hours and for AM, Normal, and PM peak hours. And then, the model is prepared for forecasting scenarios with increased truck percentages. After that, the results are compared to the base scenario and the remaining scenarios to determine the effects of dedicated truck lane technology.

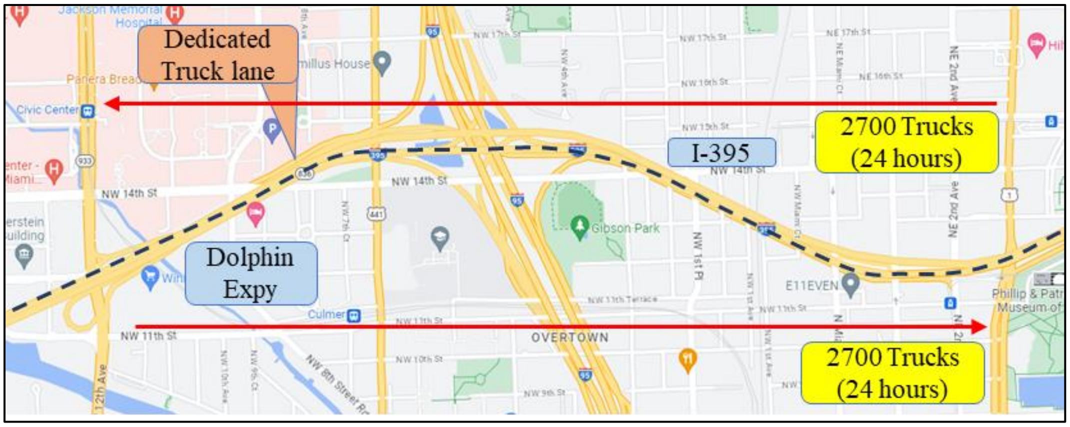

Figure 10: Dedicated truck lane (Source: Google Map)

In the microsimulation model, trucks are restricted to specific lanes that are allocated for their usage. These lanes do not have physical barriers separating them from the main traffic lanes, and other vehicles are prohibited from using these restricted lanes. In the microsimulation model, the dedicated lane originates at the left lane of the Dolphin Expressway and extends to I-395, both eastbound and westbound, as shown in the network in Figure 9. This strategy aims to segregate trucks to diminish their safety impact and mitigate potential clashes between cars and trucks. The left lane may also use the name reserved capacity truck lanes, providing truck access to relieve main lane congestion.

2.8.3 SCENARIO III- Lane restrictions

In the microsimulation model freeway lane restrictions are applied as a management strategy that confines specific types of vehicles, such as trucks and cars, to specific lanes. The prominent presence of trucks on the Dolphin Expressway and I-395 may negatively impact the speed, convenience, and comfort experienced by other vehicle drivers. In the simulation model, the left lane is restricted for truck use, and other vehicles are allowed to share any lane with trucks. Notably, there are no lane restrictions for trucks entering or exiting the freeway, thus permitting them to switch to the right lane to take an exit or to occupy the right lane briefly upon entering the freeway.

2.8.4 SCENARIO IV- Truck Exclusive Lane

Exclusive truck lanes are facilities specifically designed to be used only by trucks and are typically separated from the mainline traffic. On the Dolphin Expressway, a truck-exclusive lane is provided on the left side, isolated from the existing lanes, serving as a toll route for trucks proceeding towards the Miami tunnel. As the volume of traffic increases and the need for extra capacity arises, independent lanes for passenger vehicles can be constructed. Consequently, trucks and cars will travel on separate, dedicated roadways.

2.8.5 SCENARIO V- Truck Platoons

There is a growing demand for moving goods which has led to more trucks on the roads. This case study is mainly chosen due to the heavy truck traffic around the Port of Miami area. In our study, the third scenario introduces the utilization of truck platoons on the freeway. In the microsimulation model, the AV aggressive (CoExit) driving behavior is selected for the Automated Truck platoon vehicle, with a maximum of seven trucks designated for each platoon formation. All other standard parameters for driving behavior are taken into account. The built-in car-following driving behavior models in VISSIM 2023, namely Wiedemann 99 (an improved model of Wiedemann 74 suitable for freeway vehicle simulation), are used. Furthermore, a simplified platooning feature is integrated and tested in VISSIM 2023 Microsimulation Platform to assess the effects of platooning on the network traffic. This in-built feature manages all driving behaviors of the vehicles in a platoon, conforming to the default car-following and lane-changing models of VISSIM.

On the freeway, the lane behavior is considered AV aggressive (CoExit), whereas arterial roads are treated as Urban Motorways. Trucks arriving from the port and those using the Miami tunnel will form platoons. Similarly, trucks that use the freeway and then the Miami tunnel will assemble into platoons. And the truck platoons are going to be separated whenever they want to take an exit from the freeway. Given the high traffic congestion in the residential areas near the Miami port, trucks will refrain from forming platoons in these areas and will form platoons only on the freeway. The model is then run for AM peak hour, PM peak hour, and regular hours, and also for future forecasting scenarios. Figure 11 illustrates the formation of Truck Platoons on the freeway as per the VISSIM microsimulation model.

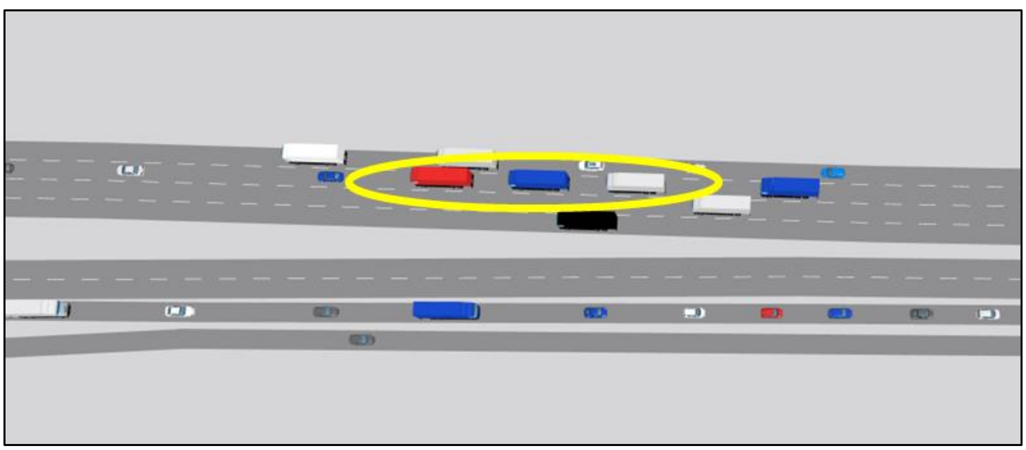

Figure 11: Platoon Formation in Microsimulation Model

2.8.6 SCENARIO VI- Truck Platoons (Truck Only Lane)

Following the previous scenario V, the scenario is run with a dedicated truck-only lane where the truck platoons could travel and exclusively use the left lane, as mentioned in the previous scenario II.

2.8.7 SCENARIO VII- Truck Platoons (Lane Restrictions)

Following the previous scenario V, the model is run with the Lane restriction scenario where the truck platoons are confined to the left lane. Still, all other vehicles can select any lane, as mentioned in scenario III.

2.8.8 SCENARIO VIII- Vehicle Platoons

In this scenario, on the microsimulation platform, trucks and a certain percentage of cars are assumed to be autonomous vehicles that will form platoons on the freeway. Autonomous vehicle platooning has emerged as a significant focus of research and development in recent years, potentially transforming the transport system. It's important to note that a key aspect of this study is to consider the environmental impact. Platooning can lead to lower fuel consumption and emissions due to reduced air resistance when vehicles drive in close proximity. VISSIM has the capability to model this effect and estimate the potential environmental advantages of autonomous vehicle platooning on freeways.

In the microsimulation model, the driving behavior AV aggressive (CoExit) is assigned to two types of vehicles: Trucks and 10% of Cars on the road that are going to use the major freeway of the developed model, including Dolphin Expressway, I-395, and I-95 near the Port of Miami. This study intends to examine the behavior of Car Platoons on the freeway and how it affects the overall network condition. That is why we make assumptions to consider 10% of the cars will try to form a platoon when traveling on a major freeway. Whenever the vehicles find sufficient space, they form Platoons with a maximum of seven platoons possible. The microsimulation model takes into account all of these parameters. All other lane-changing information remains the same as in the previous scenario III. The Vehicle Platoon model is run for two hours, with ten replications and a random seed increment. These runs are conducted for AM Peak hour, Normal hour, PM peak hour, and finally for the Forecasting model.

4. Results & Analysis

This chapter discusses the results of the simulations performed on the case study presented in the previous chapter. More specifically, the main focus is on comparing the outcomes of the base scenario with additional scenarios that have integrated various strategic implementations. The results' basis for comparison is travel time and delay across different scenarios, as detailed in the previous section. The simulations represent the A.M. peak morning hour, the Normal hour during the day, and the P.M. peak evening hour, and each scenario is run ten times with randomly seeded simulations while maintaining the same sequence of random seeds across all scenarios. Each simulation runs for two hours, and the results are averaged and segmented into individual categories.

The findings of the study are intended to shed light on the effects and potential implications of employing various techniques in a congested area near the port. The findings from the analysis are reported separately for each scenario and the entire traffic network. The goal of the analysis is to demonstrate that introducing a range of scenarios to enhance truck movement efficiency provides efficient transportation connectivity and has a favorable impact on overall crowded circumstances. Measure of Effectiveness (MOE) is a metric used in traffic engineering and transportation planning to assess the effectiveness of transportation systems. Various MOEs can be employed, and the choice is frequently influenced by the study's specific aims, including average travel speed, vehicle density, hours and cost of user delay, queue, and travel time reliability. MOEs relating to travel time and delay are discussed in the context of this study, which involves truck traffic and the implementation of strategies like dedicated truck lanes and truck platoons (FDM 11-5 General Design Considerations, 2020). The results of the simulations are described following, separated into multiple scenarios.

5.1 Travel Time Analysis

In this analysis, travel time measurements are taken from the network segments created in the VISSIM Microsimulation model near the port of the Miami area. As mentioned in the previous chapter, the average travel time calculations for all scenarios are measured for eight directions from the model nearby port of Miami. These average times, obtained from the simulations, are outlined in Table 4 for current operational traffic scenarios and Table 5 for forecasting traffic scenarios. These tables record travel times in minutes, illustrating the outcomes of the various implemented strategies.

The analysis has yielded a range of results, with some scenarios showing promising improvements and others demonstrating less favorable outcomes. Regardless, improvements are noticeable across most conditions, affirming the potential of the various strategies. Yet, the extent of change has varied. Some scenarios showed marginal differences before and after the implementation of strategies, while in some cases, they are approximately neutral. These neutral results are typically associated with the configuration of intersections and specific turning movements, particularly noticeable on Port Blvd and Biscayne Blvd. This is because the strategies are only implemented in the freeway segments. It's evident that further study of these models is warranted to gain a deeper understanding of these neutral results and to devise strategies that can contribute more significantly to travel time reduction and overall traffic management efficiency.

Table 4: Average Travel Time (minutes) Per Segment - Current Traffic Condition

Segments	Scenarios	1	2	3	4	5	6	7	8
Dolphin Expy-Tunnel (EB)	AM	20.3	18.4	19.9	21.7	19.7	19.3	20.7	18.6
	Normal	22.5	20.8	21.2	21.8	20.8	20.0	21.3	19.8
	PM	22.2	19.1	20.5	21.3	20.4	20.9	21.8	18.8
Dolphin Expy-Tunnel (WB)	AM	10.3	9.5	9.8	10.2	9.4	8.9	9.3	9.3
	Normal	13.1	12.9	12.9	13.0	12.5	12.5	13.1	13.2
	PM	13.3	13.2	13.7	14.0	13.0	12.2	12.6	12.3
Port Blvd (EB)	AM	4.0	4.0	4.0	4.0	3.9	3.9	3.9	3.9
	Normal	4.1	4.0	4.0	4.0	3.9	3.9	3.9	3.9
	PM	4.1	4.0	4.0	4.0	3.9	3.9	3.9	3.9
Port Blvd (WB)	AM	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
	Normal	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
	PM	2.1	2.1	2.1	2.1	2.2	2.2	2.2	2.2
I-95-Biscayne Blvd (NB)	AM	9.8	9.3	9.4	9.5	8.2	8.1	8.2	8.0
	Normal	18.0	18.9	17.2	18.2	14.9	15.0	14.9	14.7
	PM	22.1	20.9	21.4	21.7	17.1	16.9	16.7	16.5
I-95-Biscayne Blvd (SB)	AM	15.0	14.7	14.6	14.7	14.9	14.9	15.0	14.7
	Normal	14.7	16.5	14.8	14.6	14.8	15.0	15.0	14.6
	PM	21.0	20.0	20.7	20.6	21.0	20.2	21.0	20.1
I-95-Tunnel (EB)	AM	8.8	8.3	8.4	8.4	8.1	7.9	8.1	8.0
	Normal	11.6	12.0	10.8	11.3	9.9	9.8	10.0	9.8
	PM	14.3	13.2	13.4	12.8	12.5	12.3	12.5	12.3
I-95-Tunnel (WB)	AM	12.7	13.5	13.2	13.1	13.4	13.5	13.6	13.4
	Normal	15.0	14.4	14.0	14.2	14.9	15.1	15.5	14.8
	PM	15.8	14.7	14.8	15.0	15.8	15.6	15.7	15.3

Table 4 illustrates how implementing different strategies change vehicle travel times for current operational traffic conditions: such as implementing a dedicated truck lane can reduce travel times ranging from 3.1% to 16.3% (EB) and from 1.05% to 8.5% (WB). When trucks are using the dedicated truck only lane it improves the traffic condition with a maximum travel time reduction of 16% in the EB direction compared to the lane restrictions and exclusive lane. A truck platoon strategy on the freeway reduces vehicle travel times from 1.7% to 12.6% in the EB direction and a maximum of 16.1% in the WB direction when vehicles use Dolphin Expressway through I-395. And Using a truck platoon reduces vehicle travel times by a maximum of 17.9% in the EB when vehicles are traveling using I-95. When truck platoons use a dedicated truck-only lane, it provides better than a dedicated lane shared with other vehicles.

Additionally, using the vehicle platoon strategy results in a maximum travel time reduction of 18.4% in the EB direction and 10.8% in the WB direction. These Scenarios demonstrate neutral results for vehicles traveling on Port Blvd and Biscayne Blvd, due to the changes targeting freeways, specifically those using the Miami tunnel. The truck platoon formation shows benefits for vehicles using I-95 to Biscayne Blvd, with a reduction of around 20% in the NB direction during normal and AM peak hours and up to 30% for PM peak hours. The combined implementation of Truck Platoons and Car Platoons significantly improves travel times over any individual strategy. Figure 12 visually presents the outcomes of different strategies. The graphic illustrates the fluctuating results of these strategic measures. For road segments 3 and 4, the outcomes appear neutral across the strategies. In some instances, the changes indicated are minimal, demonstrating neutral impacts, while in others, no significant improvements are detected.

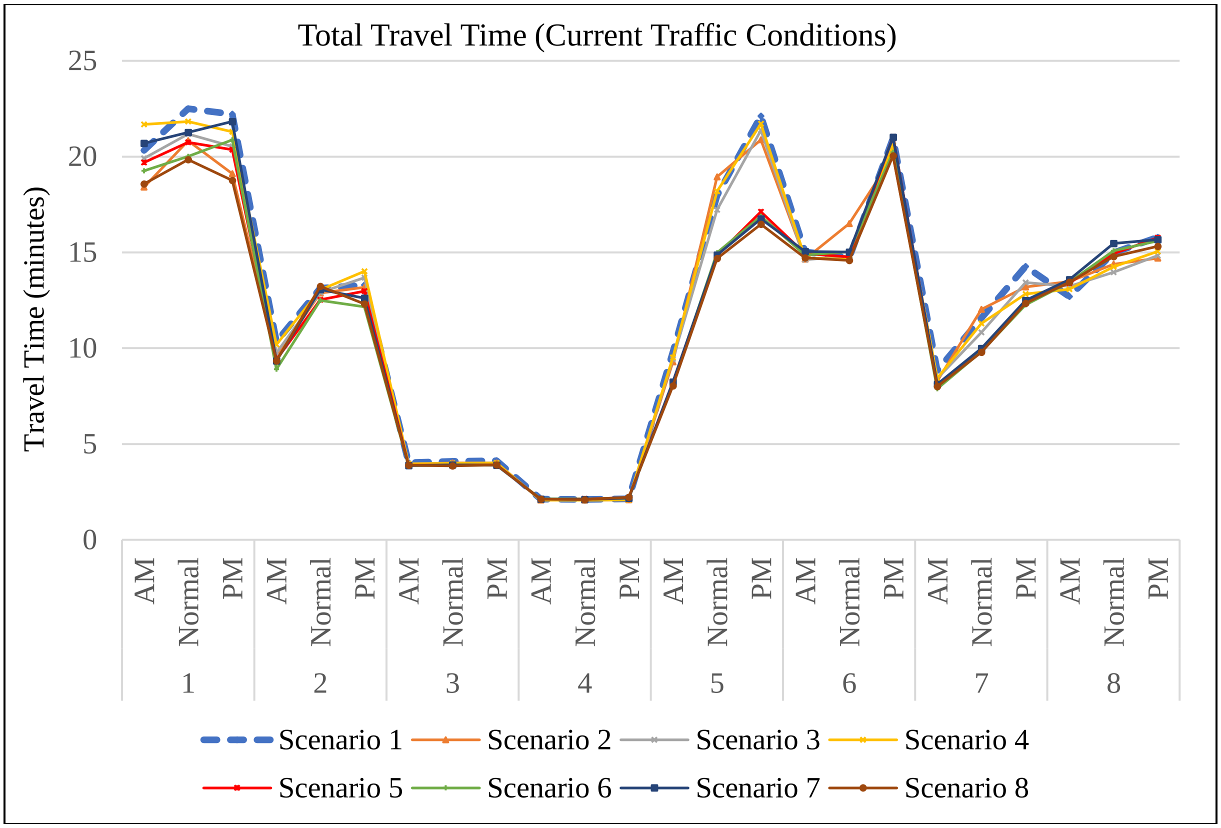

Figure 12: Average Total Travel Time - Current Traffic Conditions

Table 5: Average Travel Time (minutes) Per Segment -Traffic Forecasting Conditions

Segments	Scenarios	1	2	3	4	5	6	7	8
Dolphin Expy-Tunnel (EB)	AM	20.50	19.03	20.04	20.44	20.73	19.22	20.84	18.56
	Normal	22.96	21.07	20.71	21.40	20.23	20.45	21.21	19.92
	PM	22.81	19.46	21.35	22.33	22.61	21.41	22.60	20.23
Dolphin Expy-Tunnel (WB)	AM	10.33	9.41	10.07	10.49	10.07	8.94	9.97	10.07
	Normal	12.50	12.59	13.06	13.34	8.99	11.85	12.61	12.13
	PM	13.07	13.27	13.69	13.15	12.76	11.99	13.23	13.43
Port Blvd (EB)	AM	4.03	3.95	3.96	3.96	3.93	3.90	3.88	3.89
	Normal	4.12	4.05	3.98	4.06	3.89	3.94	3.92	3.92
	PM	4.10	4.03	4.00	3.98	3.91	3.92	3.92	3.90
Port Blvd (WB)	AM	2.12	2.09	2.08	2.07	2.17	2.13	2.13	2.11
	Normal	2.12	2.10	2.09	2.09	2.13	2.18	2.15	2.21
	PM	2.13	2.09	2.09	2.09	2.19	2.19	2.18	2.17
I-95-Biscayne Blvd (NB)	AM	9.63	9.45	9.61	9.39	8.79	8.14	8.21	8.32
	Normal	17.98	17.80	17.65	17.37	14.66	15.68	15.72	15.65
	PM	22.14	20.43	21.60	20.67	16.93	16.90	17.36	16.83
I-95-Biscayne Blvd (SB)	AM	15.15	14.79	14.71	14.68	15.10	14.87	15.48	15.49
	Normal	15.07	15.75	15.08	14.60	15.45	15.03	15.26	15.17
	PM	21.12	19.91	20.73	19.74	20.94	21.02	20.81	20.83
I-95-Tunnel (EB)	AM	8.83	8.32	8.46	8.42	8.34	8.17	8.04	8.19
	Normal	11.71	12.42	11.20	11.03	9.77	10.03	9.99	9.94
	PM	14.23	12.90	13.56	13.28	12.61	12.58	12.71	12.22
I-95-Tunnel (WB)	AM	12.86	12.05	12.36	11.10	12.93	12.01	12.02	11.72
	Normal	15.13	14.61	13.99	13.85	12.44	15.63	15.45	15.27
	PM	15.82	14.67	15.18	14.86	15.98	15.94	15.66	15.94

Table 5 presents vehicle travel time results of different scenarios for forecasting traffic conditions with increased truck volumes. It indicates how implementing strategies can reduce travel time across different traffic scenarios and times of the day. Implementing a dedicated truck lane, for example, can reduce vehicle travel times from 2.1% to 17.2% (EB) and 2.5% to 9.8% (WB) when vehicles use Dolphin Expressway. Dedicated truck lanes improve the traffic condition compared to the lane restrictions and exclusive lanes maximum of 17.2% in EB and 9.8% in WB directions. In the forecasting scenarios, truck volume increases, so using a truck-only lane reduces the interaction between trucks and other vehicles.

In some cases, when trucks use the dedicated truck lane for the forecasting traffic condition, it provides benefits by reducing the travel time compared to the current operational traffic condition. Using Truck Platoon on the freeway reduces vehicle travel times by 13.9% in the EB, and 39% in the WB direction when vehicles are using Dolphin Expressway, and using Truck Platoon reduces vehicle travel times by a maximum of 19.9% in the EB and 21.6% in the WB directions when vehicles are traveling using I-95. Using a dedicated lane for truck platoons shared with other vehicles reduces travel time by 17.3% in the EB and 7% in the WB direction, while vehicle platoons on the road reduce travel time by up to 19.9% in the EB direction and 9.8% in WB direction when vehicles are using I-95 through Miami Tunnel. A graphical representation of these scenarios results are shown in the following Figure 13.

Figure 13 illustrates that road Segment 5 shows reductions in vehicle travel time in some of the strategies. The Truck Platoon formation, in particular, offers significant advantages when vehicles are using i-95 to Biscayne Blvd, with benefits of 20% to 30% in the NB direction for normal and PM traffic conditions and a maximum of 18% for the AM peak hour. All of the scenarios provide neutral results for the vehicle traveling in Port Blvd. and Biscayne Blvd. because the changes are only made to the freeway especially for the vehicle using the Miami Tunnel.

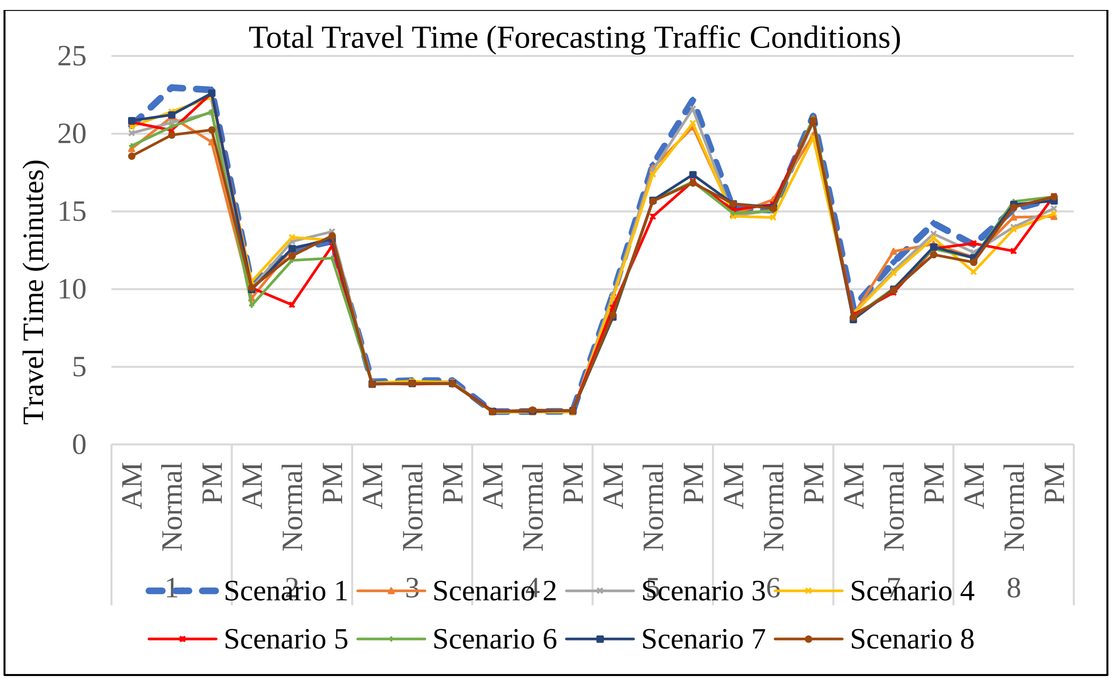

Figure 13: Average Total Travel Time - Forecasting Traffic Conditions

The comparison of maximum average total travel time reduction in percentages for different scenarios in EB and WB directions when vehicles are using Dolphin Expressway, are illustrated in Figure 14 for current operational traffic conditions and forecasting traffic. For current traffic conditions, truck only lane, truck platoons, and truck platoons with dedicated lane result in a significant reduction in travel time in the eastbound (EB) direction compared to other scenarios. However, in the forecasting scenario, vehicle platoons demonstrate better performance. Truck platoons provide superior results for the WB direction under the current traffic conditions and the forecasting scenario. Also, vehicle platoons show better results in forecasting traffic conditions.

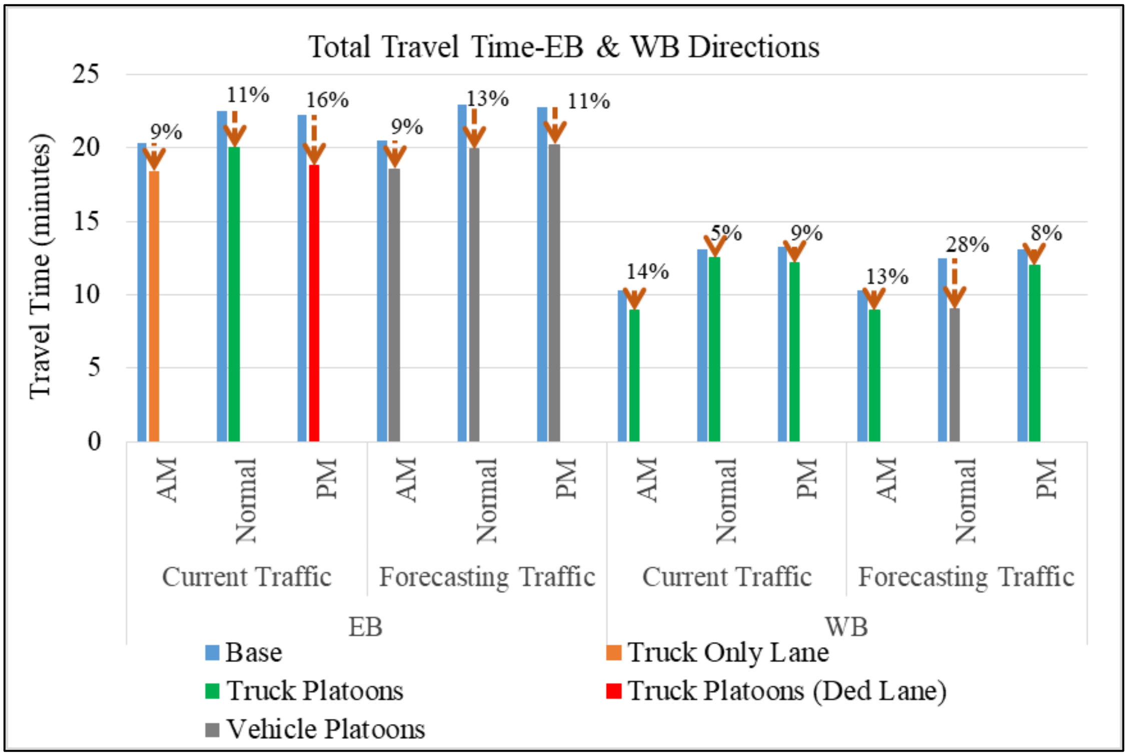

Figure 14: Total Travel Time for Current & Forecasting Traffic - EB & WB Directions

5.2 Delay Analysis

The analysis of delays is a standard measure used to assess the benefits of improving the efficiency of vehicle movement. In the study, different scenarios, such as implementing dedicated truck lanes and using truck platoons, showed positive impacts, while specific scenarios reported neutral impacts in vehicle delays. Compared to the base scenario, for current traffic conditions, some of the scenarios tested demonstrated promising results, suggesting that these strategies could improve the overall traffic flow. These scenarios successfully reduce delay times, offering a potentially potent strategy for managing heavy traffic. Table 6 and Table 7 represent a detailed overview of the average delay times in minutes for each scenario, considering current and forecasting traffic conditions, thereby offering a comprehensive dataset for future traffic management and infrastructure planning research.

Table 6: Average Delay (minutes) Per Segment - Current Traffic Condition

Segments	Scenarios	1	2	3	4	5	6	7	8
Dolphin Expy-Tunnel (EB)	AM	3.2	2.7	2.9	3.3	2.6	2.0	3.1	3.2
	Normal	5.5	5.6	5.6	5.7	5.2	4.6	5.3	4.8
	PM	6.2	6.4	6.8	7.2	6.1	5.1	6.3	6.6
Dolphin Expy-Tunnel (WB)	AM	9.9	8.5	10.0	10.1	9.7	9.3	10.9	8.4
	Normal	11.7	10.0	10.3	9.3	9.9	9.7	10.3	9.2
	PM	11.5	9.1	10.6	9.7	10.3	11.5	12.7	10.1
Port Blvd (EB)	AM	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5
	Normal	0.6	0.6	0.6	0.6	0.5	0.6	0.6	0.6
	PM	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Port Blvd (WB)	AM	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	Normal	0.4	0.4	0.4	0.4	0.4	0.5	0.4	0.5
	PM	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5
I-95-Biscayne Blvd (NB)	AM	5.2	4.8	5.0	5.1	3.8	3.8	3.8	4.0
	Normal	13.3	14.5	12.8	13.7	12.7	12.8	12.8	12.8
	PM	17.4	16.4	16.9	17.2	12.9	12.6	13.2	12.5
I-95-Biscayne Blvd (SB)	AM	9.9	9.8	9.7	9.8	9.9	9.8	10.5	10.5
	Normal	9.6	11.6	9.9	9.8	9.8	10.0	10.3	10.2
	PM	15.8	15.1	15.8	15.7	16.0	16.0	15.8	15.8
I-95-Tunnel (EB)	AM	3.5	3.7	3.6	3.8	3.4	3.4	3.4	3.1
	Normal	5.8	5.3	4.9	5.2	5.8	6.4	6.2	6.1
	PM	6.5	6.0	6.2	6.4	7.1	7.3	7.0	7.3
I-95-Tunnel (WB)	AM	2.0	1.8	1.9	1.8	1.6	1.6	1.6	1.7
	Normal	4.4	5.0	3.9	4.2	3.3	3.3	3.2	3.3
	PM	7.1	6.4	6.7	6.1	4.7	4.5	4.7	4.8

Table 6 shows the average delay measurements in minutes for each strategic approach for analyzing the current traffic situation. The Table's review reveals that some scenarios have improved average delays for all vehicles compared to the base model. Notably, From Table 6, implementing the Dedicated Truck Lane strategy within the current traffic condition results in substantial decreases in vehicle delays by 16.76% in the EB direction and between 20.41% in the EB direction. This positive impact is amplified when trucks use dedicated lanes solely or share these lanes with other vehicles, reducing delay compared to truck-exclusive lanes. Truck exclusive lane is not showing any improvements because it is only implemented on a very short length of the Dolphin Expressway. Truck Platoon on the freeway reduces vehicle travel delays by 18% to 39% in the EB and 11% to 16% in the WB direction when vehicles use Dolphin Expressway.

Furthermore, when vehicles travel WB on I-95, this strategy reduces delay times by 36%. However, these scenarios have limited impact on Port Blvd and Biscayne Blvd, as enhancements are predominantly targeted at freeway systems, notably benefiting vehicles traveling towards the Miami tunnel. Graphical representation of these scenarios results are shown in the following Figure 15. It shows that the delay results remain unchanged in segments 3 and 4. Using vehicle platoon shows a 12% to 21% reduction in both EB and WB direction when vehicles use Dolphin Expressway and 10% to 31% when using I-95.

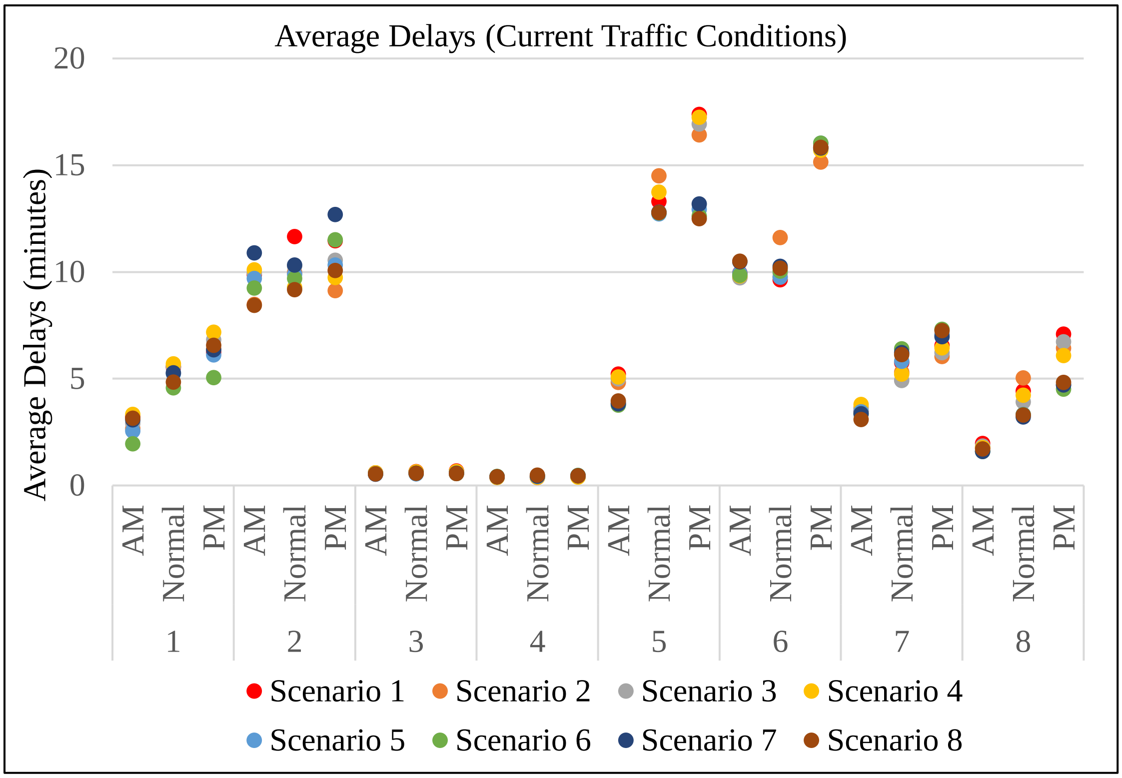

Figure 15: Average Delays - Current Traffic Conditions

Table 7: Average Delays (minutes) Per Segment -Traffic Forecasting Conditions

Segments	Scenarios	1	2	3	4	5	6	7	8
Dolphin Expy-Tunnel (EB)	AM	3.55	2.54	3.21	3.62	3.90	2.95	3.07	3.16
	Normal	5.57	5.75	6.20	6.52	4.15	4.96	5.72	5.25
	PM	5.74	6.43	6.84	6.27	5.90	5.06	6.35	6.56
Dolphin Expy-Tunnel (WB)	AM	9.26	9.12	9.10	9.94	10.02	9.25	10.06	8.44
	Normal	12.22	11.06	10.64	9.80	10.26	10.52	11.20	9.94
	PM	12.11	9.46	11.40	10.77	12.63	11.50	12.69	10.06
Port Blvd (EB)	AM	0.58	0.57	0.58	0.58	0.57	0.54	0.53	0.54
	Normal	0.67	0.66	0.62	0.67	0.54	0.58	0.57	0.57
	PM	0.65	0.65	0.64	0.61	0.56	0.56	0.57	0.55
Port Blvd (WB)	AM	0.39	0.39	0.39	0.38	0.45	0.42	0.41	0.40
	Normal	0.39	0.41	0.40	0.40	0.42	0.46	0.44	0.48
	PM	0.40	0.40	0.40	0.40	0.46	0.46	0.45	0.45
I-95-Biscayne Blvd (NB)	AM	5.05	4.98	5.16	4.94	4.44	3.77	3.83	3.96
	Normal	13.30	15.03	13.24	12.93	12.73	12.79	12.80	12.81
	PM	17.27	15.99	17.15	16.23	13.38	13.38	13.60	13.33
I-95-Biscayne Blvd (SB)	AM	10.06	9.91	9.81	9.80	10.12	9.84	10.48	10.50
	Normal	9.98	12.62	10.19	9.71	10.45	10.04	10.26	10.17
	PM	15.98	15.05	15.85	14.86	15.96	16.03	15.80	15.84
I-95-Tunnel (EB)	AM	3.61	3.41	3.71	2.48	3.34	3.36	3.35	3.09
	Normal	5.93	5.99	5.37	5.26	3.75	6.95	6.75	6.66
	PM	6.58	6.06	6.52	6.23	7.28	7.31	6.98	7.26
I-95-Tunnel (WB)	AM	1.89	1.78	1.88	1.81	1.78	1.65	1.65	1.78
	Normal	4.54	5.75	4.67	4.32	1.58	1.86	1.75	1.85
	PM	7.00	6.13	6.75	6.55	4.66	4.70	4.91	4.99

Table 7 demonstrates the impact of these strategic interventions on forecasting traffic conditions with increased truck volumes, translating into substantial delay reductions. For example, the deployment of a Dedicated Truck Lane under this forecasted traffic scenario has resulted in a reduction of vehicle delays from 9.62% to 28.46% in the EB direction and from 19.34% to 21.56% in the WB direction when vehicles are using Dolphin Expressway.
When trucks use the dedicated truck lane for the forecasting traffic condition, it provides benefits in delay reduction compared to the current operational traffic condition. Additionally, implementing a Truck Exclusive Lane has only proven beneficial, reducing delays by 19.7% in the WB direction when vehicles use Dolphin Expressway. Truck Platooning on the freeway also decreased vehicle delays by 25% in the EB and 16% in the WB on the same roadway. Furthermore, using vehicle platoons has reduced delays by 11% to 18% in both directions. Still, it yielded notable reductions in vehicle delays, by a maximum of 14% in the EB and 59% in WB when vehicles are traveling using I-95. Despite these improvements, the strategies have limited impact on Port Blvd and Biscayne Blvd, where most changes focus on freeway systems, particularly benefiting vehicles using the Miami tunnel. Graphical representation of these scenarios results are shown in the following Figure 16.

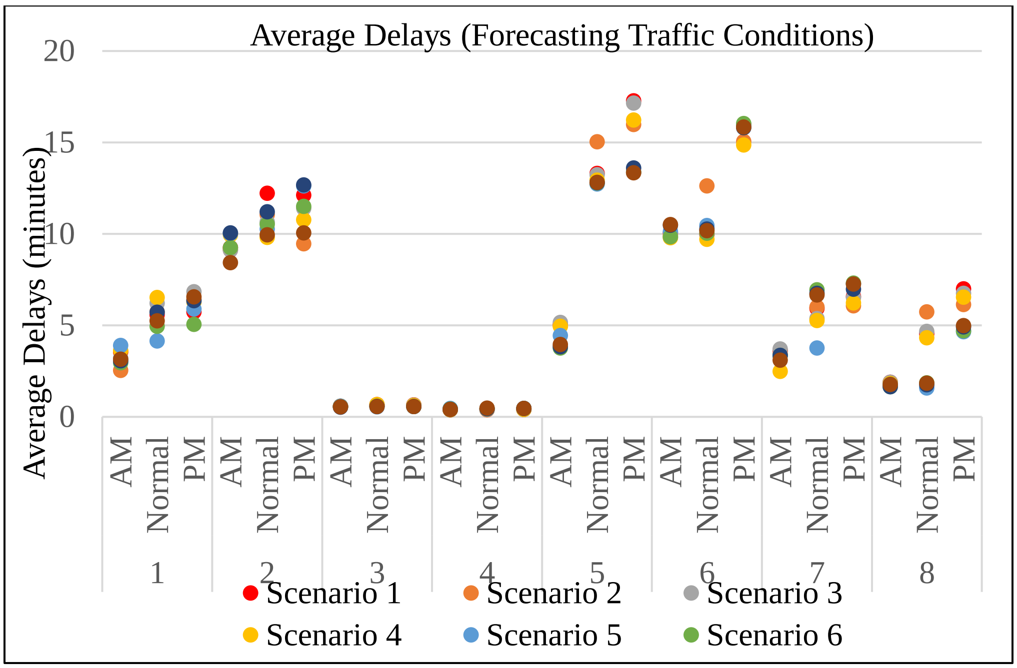

Figure 16: Average Delays - Forecasting Traffic Conditions

The comparison of maximum average delay reduction for different scenarios in EB and WB directions when vehicles are using Dolphin Expressway is illustrated in Figure 17 for both current operational traffic conditions and forecasting traffic. Implementing Truck Platoons with dedicated truck lanes results in a considerable reduction in delays in the EB direction compared to other scenarios for both current and forecasting traffic conditions. For the WB direction, truck-only lane and vehicle platoons show a significant reduction for current traffic conditions, and for the forecasting traffic implementing truck-only lane, lane restrictions, and vehicle platoons show significant reductions in delays.

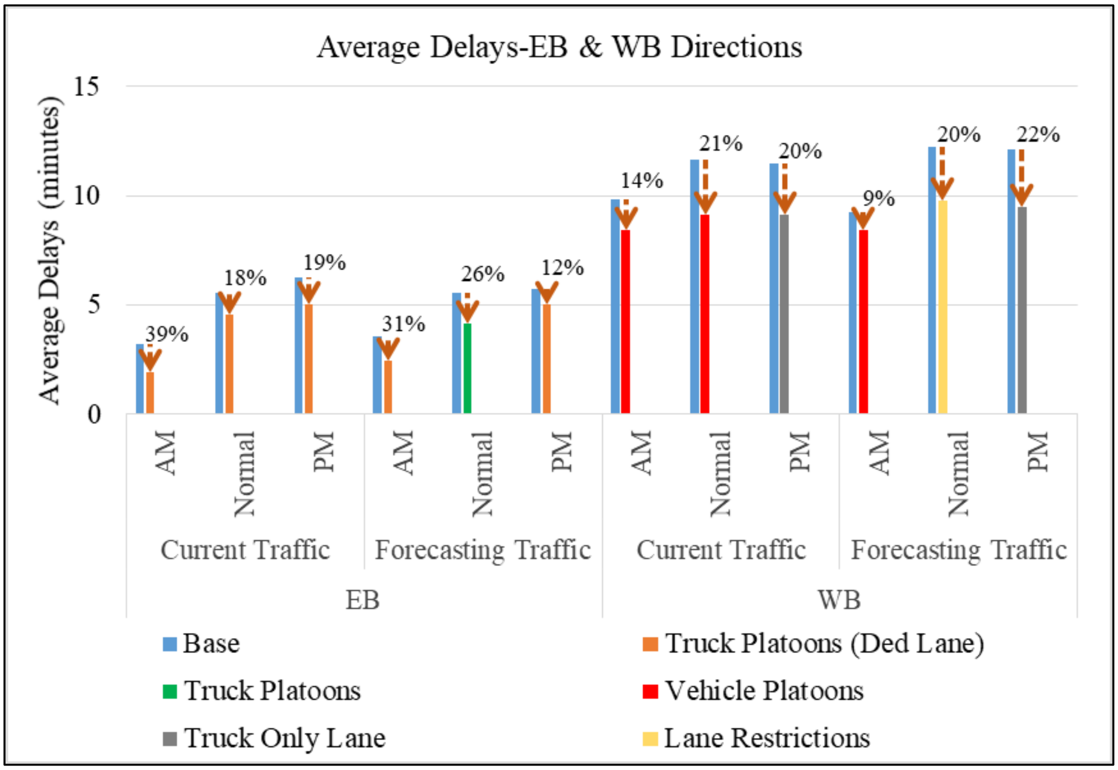

Figure 17: Average Delay for Current & Forecasting Traffic - EB & WB Directions

5. Conclusion

5.1 Study Overview

Intermodal facilities, in which various modes of transportation converge to facilitate the transfer of products, play a crucial role in U.S. commerce. These facilities include ports, rail yards, and transport terminals, constituting essential nodes in the global supply chain. Ports are crucial to the economy and trade of the United States, accounting for practically all international trade. However, they are having difficulty managing increased freight volumes, causing delays and increased expenses. Trucks, responsible for moving 72.5% of all U.S. freight by weight, face longer wait times and consume more fuel due to port congestion. This issue also has significant environmental implications, as heavy-duty trucks contribute significantly to greenhouse gas emissions and local air pollution. The communities that surround these areas suffer health and quality of life consequences. Additionally, port congestion affects truck drivers' earnings, as they're commonly paid per trip rather than hourly. Rising truck traffic due to increased port activity also leads to broader traffic congestion and elevated pollution levels. Hence, there's a need for effective management of truck movements and parking strategies to alleviate these issues, improve port operations, and maintain U.S. competitiveness in global trade.

This study develops a concept of operation to enhance the truck movement around intermodal facilities and also conducts a traffic impact analysis to improve the heavy truck operation efficiency around a specific port area based on traffic data using microsimulation platform. The purpose of the first part of the research is to identify existing freight operation planning details and develop a concept of operation considering the environmental issues created because of heavy truck movement and equity problems faced by truck drivers and people living around the port area. The main objective of this study is to recommend some guidelines about freight planning to maintain a proper freight operation. The concept proposes a flexible technology-oriented system to streamline heavy truck traffic at U.S. port intermodal facilities, aiming to reduce congestion, waiting times at the terminal gate, and environmental impact. The system includes scheduled appointments for truck arrivals and departures, proper truck parking stops and rest areas near ports to prevent parking in the residential area, real-time information regarding road conditions and driver route planning using GPS, sensors, and traffic monitoring systems. Integrating dedicated and exclusive truck lanes and lane restrictions during peak hours reduces traffic conflicts and accidents. An innovative feature of this plan is the implementation of Autonomous Truck Platooning, where self-driving trucks maintain consistent speed and distance from each other in designated zones. These proposed changes aim to increase efficiency and provide equal access to resources and opportunities for all stakeholders. The proposed system comprises three main user groups, and these are the Trucking Company and Operations Managers who oversee trip planning and communication with drivers, the Truck Drivers who transport goods and materials, and other personnel, including residents of port communities and staff at state DOTs, regional MPOs, and TMCs.

The system aims to enhance real-time communication, route planning, and safety measures, integrating various resources and tools to facilitate these processes. The idea needs to be incorporated with the existing Freight-Specific Dynamic Travel Planning application, enabling real-time tracking and coordination of truck movements. This involves using data sources related to traffic and Intelligent Transportation Systems managed by a Transportation Information Center that acquires, processes and redistributes this data. The system also incorporates a Freight Management Center that offers real-time routing data and information on vehicle and freight equipment locations. Other key Management Centers included are the Traffic Management Center, Emergency Management Center, Construction Management and Weather Service System, and Truck Parking Management system. These centers oversee crucial aspects like traffic control, incident management, road infrastructure development, weather data collection, and administration of parking facilities. Overall, the system aims to improve the efficiency of freight transportation, reduce environmental impact, and enhance safety.

The objective of the second part of the research is to conduct a traffic impact study to improve the efficiency of heavy truck operation. The goal is to enhance the freight mobility system, ensure an effective truck operational system, reduce the overall transport network's traffic congestion, and maintain and provide a sustainable transportation system. Therefore, a case study area is selected as the first step to find a congested freight operational area around the port and implement a few operational strategies regarding truck movement to facilitate rapid and efficient freight operations. The study employs a microsimulation model in PTV VISSIM 2023 to analyze traffic conditions around the Port of Miami area, focusing on the interactions between trucks and other vehicles. The simulation model inputs traffic volume, truck percentage, and speed data and provides recommendations for implementing different strategies to improve overall traffic condition and efficiency. The methodology starts by developing a base scenario that emulates current traffic conditions. This is important as it offers a general understanding of the road network operation and establishes a benchmark for comparing other scenarios. Subsequently, seven additional scenarios are implemented, each exploring a unique traffic management strategy. These strategies include dedicated truck-only lanes, lane restrictions, truck-exclusive lanes, and various implementations of truck platoons, truck platoons with dedicated lane and lane restrictions, and vehicle platoons. Each scenario runs for two hours, with ten replications using different random seeds to evaluate the impact on traffic flow during morning, normal, and evening peak hours. Their results are compared to the base scenario to determine their effectiveness. This methodology allows for an in-depth evaluation of how each strategy potentially improves traffic flow, road safety, and overall transport efficiency outside the Port of Miami area.

The simulations of different traffic scenarios provide critical insights into travel times and delays. Implementing strategies such as dedicated truck lanes and truck platoons for current operational traffic conditions provides significant improvements. Particularly, the strategy of a dedicated truck lane leads to a reduction in travel times ranging between 1.25% to 13.25% (EB) and 6.01% to 10.25% (WB), with truck platoon formation on freeways reducing travel times by 5% to 28% (EB) and 4% to 13% (WB). Combining the implementation of truck and car platoons results in the most substantial improvements, with the truck platoon showing significant benefits when vehicles are using i-95 to Biscayne Blvd. When forecasting traffic conditions with increased truck volumes, similar strategies show positive impacts. Dedicated truck lanes, for instance, reduced travel times from 14.23% to 30.12% (EB) and 13.33% to 17.79% (WB). Other approaches, like the usage of truck platoons, also reduce travel times, notably on freeways such as the Dolphin Expressway and i-95. Delay analysis suggests that strategies like dedicated truck lanes and truck platoons can significantly reduce vehicle delays, making these strategies viable for managing heavy traffic. Particularly, using truck platoon formation shows a remarkable reduction in delays, especially for vehicles using i-95 to Biscayne Blvd.

5.2 Key Contributions and Potential Future Extensions

In this study, we have explored a system of operations concept, and a traffic impact study related to enhancing the efficiency of heavy truck operations. The contributions of this research are multifaceted. This research study can be beneficial for trucking companies, port authorities, and truck drivers in terms of efficient freight movement and time savings. The proposed network prepared in microsimulation model represents a significant advancement in its application to real-world traffic scenarios, especially those involving trucks and autonomous vehicles nearby and mitigating adverse environmental impacts. It may also help to reduce traffic congestion and increase freight movement in densely populated areas. The approach enables more effective truck movement management and supports decision-making processes for government officials and logistics service providers. The operational concept considers the specific case study of the Port of Miami, giving a practical implementation of the recommended methods and solutions. By conducting a traffic impact study and evaluating the effectiveness of the concept, the research contributes valuable insights into the real-world implications of implementing the proposed measures. The findings can inform port authorities and stakeholders in similar areas, offering a blueprint for improving heavy truck operations and mitigating the negative impacts on congestion, emissions, and equity.

The suggested operational concept and model solution approach held significant potential for future expansion. First of all, the concept of operation guidelines can be implemented through an application package and prepare a software system so that the information can be easily transferred to the truck drivers and operational managers. Additionally, the concept can be extended to address other aspects of port operations, such as optimizing terminal operations and integrating sustainable last-mile delivery solutions. An optimized scheduling system for truck stops and rest areas can be developed in conjunction with the terminal appointment. The concept can be expanded to incorporate emerging technology trends in the transportation industry, such as truck automation and electrification. Integrating these technologies into the concept can further enhance efficiency, reduce emissions, and improve the overall sustainability of port operations. The concept of operation serves as a foundation for developing tailored solutions that can be adapted and applied to other ports, taking into account their unique characteristics and challenges.

Furthermore, the microsimulation model network can be expanded inside and outside the port area, and the strategic approach can be implemented in both the freeway's long and arterial sections. The model also offers the flexibility to analyze future traffic scenarios with varying percentages of increased vehicle volumes. In the future the simulation model can analyze rail freight network systems. Additionally, the concept can be adapted to different port locations and contexts, considering their operational requirements. Other future traffic management strategies could also be explored, such as signal timing optimization or congestion pricing in the arterial road. The research opens avenues for improving port logistics' sustainability and effectiveness and contributes to the ongoing efforts to create more resilient and efficient supply chains.

6. References

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