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EXPRESS LANES BENEFITTING FREIGHT MOBILITY: CAN EXPRESS LANE SYSTEMS AND ITS BENEFITS TO GENERAL-PURPOSE LANES IMPROVE FREIGHT MOBILITY?

FINAL REPORT

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16. Abstract

This Florida Department of Transportation (FDOT) study investigates whether Express Lane systems, and their effects on adjacent general-purpose lanes, improve freight mobility for heavy goods vehicles (HGVs) on Florida's Strategic Intermodal System (SIS), and identifies suitable simulation tools and datasets for freight research. The research combined (1) a literature review and an assessment of available data sources; (2) an empirical before-and-after analysis of travel time, speed, delay, reliability, crash rates, energy use and emissions on the I-4, I-95 and I-295 Express corridors; (3) calibration checks and incident-scenario analysis of the inherited VISSIM model of I-95 Express in FDOT District 6; (4) a technical review of five FDOT Express Lane VISSIM model packages from Districts 5 and 2; and (5) microsimulation of Express Lane pricing strategies and increased travel demand on an I-4 corridor model. Express Lane implementation was associated with measurable improvements in travel time, speed, delay and reliability on both Express Lanes and general-purpose lanes. On I-95, a long-duration two-lane incident caused severe network delay; several localized incidents had negligible effects. In the pricing and demand simulations, toll levels mainly changed lane choice and revenue, whereas demand growth was the dominant driver of general-purpose lane, network and freight deterioration, and no tested pricing strategy offset it. The findings also highlight the need for future freight-focused Express Lane research using more continuous, vehicle-class-specific data, such as truck probe trajectories, telematics, classified counts, and weigh-in-motion observations, to evaluate HGV impacts more directly.

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1 Master Executive Summary

1.1 Overview of the Research Program

This report presents the results of research conducted for the Florida Department of Transportation (FDOT) on the evaluation of express-lane impacts on freight mobility. The research program comprised three sequential deliverables (Parts I–III), a comparative review of available FDOT express-lane simulation models (Part IV), and a simulation analysis of Express Lane pricing strategies and future demand on the I-4 corridor (Task 4, Part V). Together, the five parts provide a comprehensive foundation for advancing FDOT's understanding of how express and managed lanes affect truck and freight-vehicle operations on Florida's Strategic Intermodal System (SIS).

Florida's freight transportation system is dominated by trucking, which accounts for the vast majority of freight movement by value within the state. As SIS-designated Interstate facilities have increasingly adopted express-lane and high-occupancy toll (HOT) configurations, the operational effects of these facilities on freight vehicles — particularly heavy trucks — have become a research priority. This program was designed to address that gap through a systematic combination of literature synthesis, empirical data analysis, microsimulation model development, model-package review, and simulation of pricing strategies and future demand.

1.2 Literature Review and Data Assessment

Part I of this report provides the methodological and empirical foundation for the research program. The deliverable comprises two primary tasks: a comprehensive literature review covering simulation and modeling approaches, statistical and empirical analyses, and real-world applications of express-lane evaluation; and a detailed data assessment covering ten major transportation data sources and eight Florida express-lane corridors.

The literature review identified microsimulation — particularly PTV VISSIM — as the dominant tool for evaluating express-lane performance, while also documenting the range of dynamic traffic assignment, optimization, and statistical approaches used in the field. The data assessment identified the National Performance Management Research Dataset (NPMRDS), the Florida Traffic Online portal, and the RITIS platform as the primary sources for high-frequency corridor-level performance data. Key data gaps were documented for real-time freight-vehicle classification and for crash data linked to express-lane access events.

1.3 Empirical Analysis of Express-Lane Impacts

Part II of this report builds on the data assessment in Deliverable 1 by applying an empirical before-and-after analysis to three FDOT express-lane corridors: I-4 Ultimate (SR-400), I-95 Express (SR-9), and I-295 Express East/West (SR-9A). The analysis uses RITIS-sourced travel time, speed, and reliability data and FDOT truck volume data to quantify the performance changes associated with express-lane introduction on these corridors.

The empirical analysis documents improvements in average travel time, speed, delay, and travel-time reliability on both the express lanes and adjacent general-purpose lanes following express-lane implementation. The analysis also examines truck-specific volume trends and quantifies energy consumption and emissions impacts using before-and-after traffic metrics. The three corridors studied — representing one urban freeway, one suburban freeway, and one ring road — together illustrate the range of express-lane operational contexts present on Florida's SIS network.

1.4 VISSIM Model Development and Incident Analysis

Part III applies the microsimulation approach identified in Part I to the VISSIM model of the I-95 Express corridor in FDOT District 6 (Miami-Dade County), inherited from the I-95/State Road 9 Project Development and Environment (PD&E) study.

The research team adapted and checked the inherited PD&E VISSIM model against available traffic observations. Nine incident scenarios were evaluated in the AM and PM peaks, each compared with a no-incident run that uses the same random seed and VISSIM version (10 random seeds). A long-duration two-lane general-purpose (GP) lane near-blockage (SC07) was severe in both peaks, adding about 530 (AM) and 405 (PM) vehicle-hours of in-network delay per hourly interval, or about 1,030 and 1,519 when the derived latent delay of vehicles unable to enter the network is included. Two-lane near-blockages (SC03) had clear/moderate effects, while one-lane GP, Express Lane and rubbernecking-only incidents had negligible network-wide effects. Heavy goods vehicles (HGVs) showed proportionally larger delay increases in SC07 and AM SC03, much of which reflects their exposure in the GP lanes.

1.5 Express-Lane Model Review and Comparative Assessment

Part IV of this report presents a technical review of five FDOT express-lane VISSIM model packages from two FDOT districts, conducted in parallel with the Deliverables 1 through 3 work to identify existing FDOT model resources available for freight-mobility research. The review covers SR 414/Maitland Boulevard, I-4 Ultimate, and the I-4 South Systems Interchange Modification Report (SIMR) package (District 5) and I-295 East Express and I-295 West Express (District 2).

The review found that the I-4 South SIMR package is immediately usable for freight research, with 100 directly queryable SQLite result databases confirming modeled HGV network-delay reductions of approximately 60 percent (2030 AM) and 25 percent (2030 PM) in Build versus No-Build scenarios. The I-295 East Express package requires a data export to become accessible. The I-295 West Express package has a critical stochastic sampling deficiency that must be remediated before quantitative use.

1.6 Operational Strategy and Future Demand Scenarios

Purpose. Part V of this report presents Task 4, which tested how Express Lane pricing strategies (Subtask 4.2) and higher corridor demand (Subtask 4.3) affect lane choice, revenue, corridor

operations in the Express Lanes (EL) and general-purpose (GP) lanes, and freight (heavy goods vehicle, HGV) performance on the modeled I-4 corridor. The two subtasks use the same reference runs and 12 paired seeds, so together they separate pricing-driven from demand-driven effects.

Key findings.

- **Pricing changes lane choice and revenue, not corridor operations.** At baseline demand, lower and higher toll bounds changed the average toll by -23.5% and +39.7%, transactions by +8.9% and -14.9%, and revenue by -16.6% and +18.9%. Across all pricing alternatives GP travel time changed by at most 0.8% and network delay per vehicle by at most 1.0%.
- **Demand growth drives operational and freight deterioration.** Realized demand increases of 9.57%, 18.77% and 26.87% raised network delay per vehicle by 26.2%, 78.7% and 149.1%, and eastbound HGV travel time by up to 40.2%. Express Lane speed changed by at most 3.5%.
- **The existing controller responds as designed to Express Lane density.** Express Lane density stays comparatively low, so the toll rose by at most 5.0% while GP congestion grew.
- **A GP-based toll signal is not a remedy.** GP-density-responsive pricing produced a much stronger toll response but no demonstrated operational advantage, and adverse GP effects at elevated demand.
- **Freight follows GP congestion.** HGVs remain in the GP lanes; their travel time and reliability worsen with demand, and no tested pricing change offset this.

Conclusion. Within the modeled conditions, demand growth is the dominant driver of GP, network and freight deterioration. The tested pricing strategies primarily influence lane choice and revenue rather than offsetting that deterioration. This does not make Express Lane pricing ineffective, but further operational-strategy development should address the underlying growth in corridor demand and GP congestion as well as toll magnitude or congestion signals.

Limitations and future research.

- The results are simulation-based sensitivity tests for one corridor. The 130% Demand Scenario (D130) is a valid stress scenario, not a forecast.
- Dynamic-versus-fixed time-of-day pricing is left to future work.

1.7 Summary of Key Findings

The five parts of this report collectively establish the following principal findings:

1. Express-lane corridors on Florida's SIS show measurable improvements in travel time, speed, delay, and reliability following express-lane implementation based on empirical before-and-after analysis of NPMRDS and FDOT traffic data (Deliverable 2).

2. Microsimulation, particularly VISSIM, is the established tool for evaluating express-lane operational impacts. Available FDOT VISSIM packages from two districts provide a directly accessible resource for advancing this research (Deliverables 1 and Part IV).

3. The VISSIM model for I-95 Express in District 6, inherited from the I-95/SR 9 PD&E study and adapted and checked by the research team, supports scenario-based incident-impact analysis. In paired same-seed comparisons, a long-duration two-lane GP near-blockage (SC07) was severe in both peak periods, two-lane near-blockages (SC03) had clear/moderate effects, and several localized incidents had negligible network-wide effects. In SC07 and AM SC03, HGV delay per vehicle increased proportionally more than passenger-vehicle delay, reflecting in large part the greater exposure of HGVs, which remain in the GP lanes where the incidents occur (Deliverable 3, Part III).

4. The I-4 South SIMR VISSIM package provides verified modeled evidence that HGV network delay is approximately 60 percent lower under the Build (express-lane) scenario than the No-Build scenario for the 2030 AM peak, based on 10-run arithmetic means from 100 SQLite result databases. The mechanism — direct HGV express-lane use versus general-purpose lane congestion relief — requires additional analysis (Part IV).

Figure 1 illustrates the verified modeled HGV network-delay values for all four Build-versus-No-Build scenario pairs in the I-4 South SIMR analysis. The figure compares Build (express lanes included) and No-Build (no express lanes) conditions using mean HGV network delay in seconds, averaged across 10 stochastic simulation runs per scenario. All values were extracted directly from the I-4 South SQLite result databases and verified against the QC-approved numerical findings (NF-COMB-003 through NF-COMB-010). The measure is the network-wide average delay for vehicle class 20 (HGV Type 200), which represents heavy goods vehicles in the I-4 South VISSIM model.

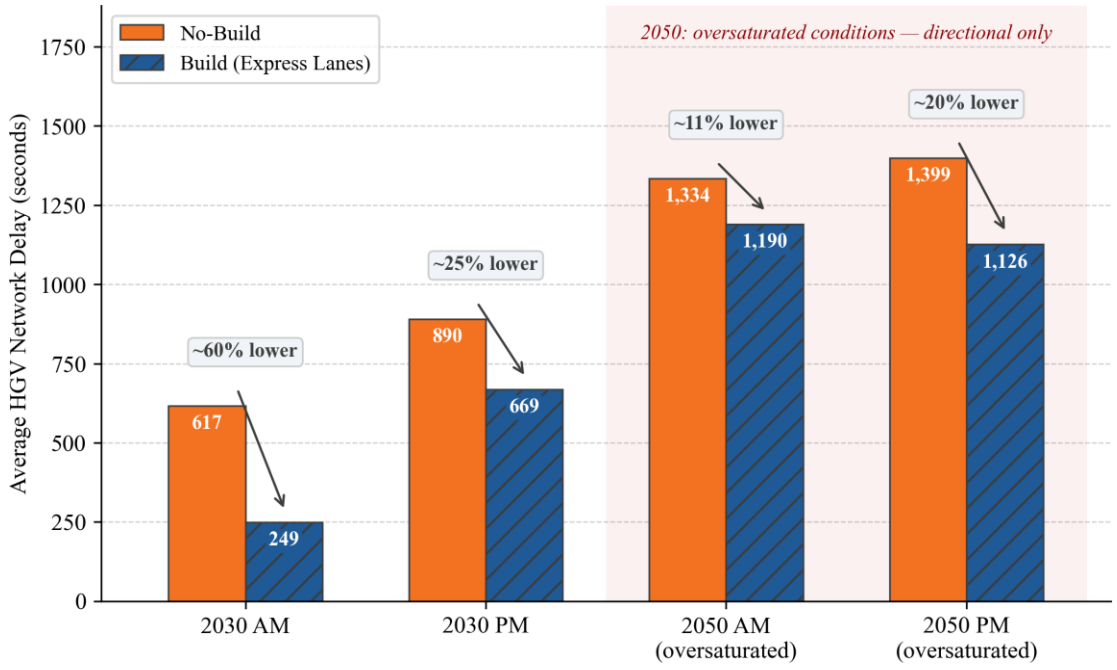

Figure 1. Modeled I-4 South SIMR HGV Network Delay: Build vs. No-Build Scenarios

Source: NF-COMB-003 through NF-COMB-010, 10 stochastic runs per scenario; vehicle class 20 (HGV Type 200). Build-versus-No-Build differences are modeled associations, not causal findings. The mechanism producing the observed delay reduction cannot be attributed solely to express-lane use — direct HGV EL routing cannot be separated from indirect GPL congestion relief, and other Build improvements may contribute. 2050 scenarios are oversaturated (network-wide HGV speeds below 20 km/h (13mph)); those results are directional only and should not be used for design purposes.

As shown in Figure 1, the largest relative difference occurs in the 2030 AM period — approximately 60 percent lower HGV network delay in the Build scenario (249.2 seconds) than in the No-Build scenario (616.7 seconds). The 2030 PM period shows approximately 25 percent lower Build delay (669.2 vs. 890.5 seconds). The 2050 AM and PM results show approximately 11 and 20 percent lower delay in Build (1,189.6 vs. 1,334.1 seconds AM; 1,126.2 vs. 1,399.2 seconds PM), respectively, but both 2050 scenarios occur under oversaturated network conditions and should be treated as directional indicators only. The findings are modeled associations. Causal attribution to express-lane use alone is not possible from static model inspection; the HGV express-lane mechanism requires a data collection point (DCP)-level query (recommended action DR-17, Table 59).

5. The I-295 East Express model provides a complete dynamic managed-lane model with explicit HGV access. All results are stored in a proprietary binary format requiring a data export request before the package is usable (Part IV).

6. All eight Build scenarios for the I-295 West Express model used exactly one stochastic run, which does not meet FDOT's minimum standard of five runs per scenario. Re-runs are required before the West package can support quantitative freight analysis (Part IV).

7. Within the modeled I-4 corridor (2040 PM peak), Express Lane pricing primarily changes lane choice, toll transactions and revenue, whereas growth in corridor demand is the dominant driver of general-purpose lane, network and freight deterioration. None of the tested pricing strategies offset that deterioration, and a GP-density-responsive pricing formulation showed no demonstrated operational advantage (Part V).

1.8 Recommended Next Steps

The research team recommends the following actions as immediate next steps:

- Calibrate the I-4 microsimulation model to reflect current roadway geometry, traffic operations, and express lane configurations.
- For future research beyond the present project, develop operational strategies that address the underlying growth in corridor demand and general-purpose lane congestion, in addition to toll magnitude or congestion signals. A comparison of dynamic and fixed time-of-day pricing would require a longer simulation window or empirical dynamic toll observations sufficient to establish representative time-of-day schedules (Part V, Section 3.4).). Future research should also consider continuous, vehicle-class-specific observed data where available, such as freight probe-vehicle trajectories, truck GPS or telematics data and weigh-in-motion records, to evaluate HGV travel time, reliability and general-purpose/managed-lane interactions more directly (Part V, Section 3.6). No additional simulation is recommended for the present project.

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Acronyms and Abbreviations

Abbreviation	Definition
AADT	Annual Average Daily Traffic
AOI	Area of Influence
ATRI	American Transportation Research Institute
BI	Buffer Index
CI	Confidence Interval
CMF	Crash Modification Factor
DCP	Data Collection Point (VISSIM)
DTA	Dynamic Traffic Assignment
EB	Eastbound
EL	Express Lane
EPA	U.S. Environmental Protection Agency
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FPID	Financial Project Identification Number
GEH	Geoffrey E. Havers calibration statistic
GP	General-Purpose (lane)
GPL	General-Purpose Lane (used interchangeably with GP)
HGV	Heavy Goods Vehicle
HOT	High-Occupancy Toll
HOV	High-Occupancy Vehicle
INPX	VISSIM network file format (XML)
JAX	Jacksonville International Airport
LOS	Level of Service
MIA	Miami International Airport
ML	Managed Lane
MOE	Measure of Effectiveness
MOVES	Motor Vehicle Emission Simulator (EPA)
NB	Northbound
NPMRDS	National Performance Management Research Dataset
O-D	Origin-Destination
PD&E	Project Development and Environment
PTI	Planning Time Index
PTV	Planung Transport Verkehr (VISSIM software developer)
RBCGUI	Ring-Barrier-Channel signal control interface
RITIS	Regional Integrated Transportation Information System
SB	Southbound
SDF	VISSIM proprietary result file format (binary)
SIS	Strategic Intermodal System
SIMR	Systems Interchange Modification Report
SOV	Single-Occupancy Vehicle
SR	State Road
TOD	Time of Day
TPA	Tampa International Airport
TTS	Travel Time in System
TTR	Travel-Time Reliability
VBScript	Visual Basic Script
VISSIM	PTV Vissim microsimulation software
VMT	Vehicle Miles Traveled
WB	Westbound

Part I

Literature Review and Data Assessment

Task 1: Literature Review, State of Practice, and Data Assessment

Part I presents the literature review and data assessment conducted as Deliverable 1 of this research program. The deliverable synthesizes peer-reviewed research, agency reports, and data-source assessments to establish the methodological framework and data foundation for the subsequent empirical analysis and model development tasks.

1 Introduction

One of the most emerging concepts among transportation policymakers is the efficient implementation of toll-managed lanes. These facilities are designed to serve a dual purpose, enhancing the capacity and performance of existing expressway systems while also generating toll revenue to support sustainable infrastructure investment (USDOT, 2012). Thus, the revenue collected can be reinvested by facility operators to fund additional traffic mitigation and mobility improvement projects, particularly in highly congested urban areas. However, it is important to highlight that the primary objective remains improving traffic conditions, as managed lanes operate alongside general-purpose lanes within the same expressway corridor. Therefore, both should be viewed as interconnected components of a single transportation system, rather than as independent entities. Any deterioration in traffic performance on one facility can quickly propagate to the other, emphasizing the need for coordinated management and evaluation (NCHRP, 2016).

Toll-managed facilities were initially introduced to provide motorists with a more time-efficient alternative during periods of congestion, while requiring a reasonable fee for this enhanced level of service. To achieve these objectives, toll-managed lanes generally follow two distinct models:

1. Congestion-management facilities, which primarily focus on mitigating traffic delays; and
2. Revenue-generation facilities, which aim to raise funds to finance the construction or maintenance of managed lanes and related highway infrastructure.

For example, congestion-management facilities often involve the conversion of existing and underutilized High-Occupancy Vehicle (HOV) lanes into High-Occupancy Toll (HOT) lanes (Regan, 2009). These HOT lanes allow access to motorists willing to pay a toll, as well as to high-occupancy vehicles, such as carpools and buses, that can use the facility free of charge or at a discounted rate. Conversely, revenue-focused facilities, including newly constructed HOT lanes, Value Pricing Lanes, or Express Toll Lanes (ETLs), are designed not only to manage congestion

but also to generate financial returns. Such lanes typically do not offer toll exemptions or discounts for high-occupancy vehicles (Poole, 2014). The motivation for emphasizing revenue generation lies in the high capital costs associated with constructing and operating these facilities. To reduce the financial burden on federal or state agencies, projects are often developed through Public-Private Partnerships (P3s). Under this framework, private investors finance construction in exchange for the right to operate and collect toll revenues for a defined concession period, typically up to 50 years (FHWA, 2016).

Over the years, particular attention has been directed toward a specific type of toll-managed facility, the Express Lanes. According to numerous transportation agencies, Express Lanes are increasingly recognized as an effective strategy to alleviate congestion, particularly in urban areas constrained by limited right-of-way, environmental considerations, policy restrictions, and high construction costs (Thomson et al., 2012). More specifically, compared to other types of managed toll facilities, Express Lanes offer a high degree of operational flexibility, allowing agencies to actively manage traffic in real time to respond to changing demand. These facilities often employ congestion-based pricing, may include vehicle eligibility restrictions, and can be operated as reversible or bi-directional flow lanes to better accommodate directional peak-hour traffic (Kadeha et al., 2020). Such flexibility enables transportation agencies to provide motorists with more reliable mobility options, characterized by predictable travel times, while also contributing to long-term congestion management, emission reductions, and enhanced support for transit operations (FDOT, 2014).

Although the concept of Express Lanes was first introduced in California in 1995, and has since been widely implemented across several states including Florida, Texas, and California, the majority of prior research has primarily focused on design standards, toll pricing mechanisms, and policy frameworks. However, the quantitative assessment of the mobility benefits, such as travel time reliability and efficiency improvements, has often remained complementary, with limited direct evaluation of their measurable impacts on roadway users (NCHRP, 2020). More specifically, a significant portion of motorists using expressway segments are freight operators, emphasizing the importance of managed-lane concepts in supporting broader regional and state goals, such as the advancement of freight mobility across federal and state transportation facilities. Freight mobility is directly linked to a region's economic competitiveness, as efficient goods movement underpins trade, logistics, and supply chain performance.

This relationship is particularly evident in Florida, a state distinguished by its integration of all four major freight transportation modes, highway, rail, maritime, and air. According to TRIP (2023), Florida's freight system handled approximately 839 million tons of freight valued at $1.1 trillion, ranking it as the eighth largest freight market in the United States. Between 2022 and 2050, freight moved annually by trucks in Florida is projected to increase by 94 percent in value (inflation-adjusted) and 58 percent in tonnage. The same report found that nine percent of total travel on Florida's Interstate highways, and 16 percent on rural Interstates, is by combination trucks, demonstrating the sector's extensive presence on the network.

The dominance of trucking in Florida's freight movement stems largely from its essential role in intermodal operations. The state's maritime and air freight systems are among the most active in the nation. According to the Florida Ports Council, the state's 16 seaports handled 113.4 million tons of cargo and 4.26 million TEUs in FY 2023–2024, while Miami International Airport (MIA) processed approximately 2.78 million tons of air cargo in 2023, maintaining its status as the #1 U.S. airport for international freight and the primary gateway for perishables, including 91% of U.S. imported cut flowers. However, the cargo entering these facilities must ultimately reach its inland destinations. This first- and last-mile connectivity is predominantly achieved by trucks, which serve as the crucial link between ports, airports, rail terminals, and distribution centers. In fact, approximately 80% of all freight tonnage in Florida is transported by truck, underscoring the importance of highway–port–rail–airport connectivity and the critical role of managed-lane systems in maintaining efficient freight movement (FDOT, 2022a).

1.1 Freight Related Challenges

The steady increase in freight volumes has placed significant strain on the national transportation network, intensifying conflicts between passenger vehicles and freight carriers on shared infrastructure (USDOT, 2017). Rapid growth in international trade has also heightened pressure on critical freight gateways, ports, airports, and border crossings, which serve as vital nodes in the intermodal system but often act as bottlenecks for goods movement. Compounding this issue, the overall transportation infrastructure has not expanded at a rate proportional to the growth in travel demand and commercial activity, creating capacity and reliability challenges across major corridors.

The American Transportation Research Institute (ATRI) has provided valuable quantitative insights into these challenges by analyzing a wide array of data sources, including its extensive truck GPS database and Operational Costs of Trucking benchmarks. According to American Transportation Research Institute (2023) analysis, while total hours of congestion slightly decreased in 2022 from record 2021 highs due to a softening freight market, the operational cost of trucking increased sharply, leading to a 15% year-over-year rise in total congestion costs. This level of delay equates to more than 430,000 commercial truck drivers sitting idle for one full work year, with an average annual cost of $7,588 per registered combination truck. More specifically, at the state level, the impact of congestion is particularly pronounced. The top 10 states each experienced trucking congestion costs exceeding $8 billion, led by Texas ($9.17B), California ($8.77B), and Florida ($8.44B). Combined, these states accounted for over half (52%) of total national congestion costs. Among metropolitan areas, New York City ($6.68B), Miami ($3.20B), and Chicago ($3.14B) recorded the highest freight-related delay costs. ATRI also estimated that in 2022, the trucking industry wasted over 6.4 billion gallons of diesel fuel due to congestion, representing $32.1 billion in excess fuel costs. Beyond economic impacts, congestion also compromises safety performance, particularly for heavy trucks that require greater stopping distances and space to maneuver. From 2017 to 2021, Florida averaged 336 fatalities annually in collisions involving heavy duty trucks, approximately 15 fatalities per 100 million population,

underscoring the pressing need for capacity, safety, and operational improvements across freight corridors.

Investments in infrastructure, particularly managed express lanes (ELs), have demonstrated significant potential to enhance goods movement efficiency, reduce congestion-related costs, and improve roadway safety at both the state and national levels. ELs employ dynamic tolling and active traffic management strategies to sustain free-flowing conditions during peak hours, minimizing travel-time variability and providing enhanced travel time reliability, which constitutes an essential parameter of freight logistics. Moreover, by reducing the interaction between heavy trucks and general-purpose traffic, these facilities contribute to improved operational efficiency and safety for all roadway users.

In Florida, the deployment of Express Lanes within major freight corridors such as I-95, I-75, and I-4 presents a strategic opportunity to enhance mobility across some of the state's most heavily congested urban areas. The I-95 Express Lanes in South Florida, for instance, have produced substantial travel-time and reliability improvements, benefiting both commuters and freight operators serving key gateways like PortMiami and Port Everglades. Following implementation, average peak-period speeds in the general-purpose lanes increased dramatically, from approximately 15 mph (southbound) and 20 mph (northbound) to 51 mph and 41 mph, respectively. During the same period, the express lanes accommodated over 7,400 vehicles during AM and PM peaks (about 28% of total I-95 volume), maintaining average speeds above 45 mph, exceeding federal HOT conversion performance standards (FDOT, 2014). Moreover, similar performance outcomes have been reported along other Florida facilities. More specifically, the I-4 Express corridor in Orlando sustained speeds of 45 mph or greater more than 98% of the time during peak hours in 2023, while the I-595 Express (Broward County) consistently achieved its ≥ 45 mph reliability target, as documented in (FDOT, 2023). Likewise, the I-75 Express Lanes have improved throughput along one of the state's primary north–south freight arteries linking major distribution centers, seaports, and inland logistics hubs.

Collectively, these ELs facilities have the potential for establishing a statewide framework for improving first- and last-mile freight connectivity, reducing delay-induced operational costs, and reinforcing Florida's long-term economic competitiveness through a more resilient, multimodal highway network. However, while these performance metrics confirm substantial mobility and reliability gains, they do not yet directly quantify the specific improvements in freight fluidity associated with each individual express-lane facility, highlighting a key gap for further investigation.

2 Literature Review

The purpose of this task is to identify and synthesize how prior studies have evaluated the impacts of Express Lanes. However, it is important to recognize that Express Lanes belong to the broader category of Managed Lanes (MLs), a family of highway facilities in which access, pricing, and eligibility are actively controlled to optimize traffic flow and reliability. Managed Lanes encompass several facility types, including:

- High-Occupancy Vehicle (HOV) lanes, which prioritize eligible carpools;
- High-Occupancy Toll (HOT) lanes, which allow tolled solo drivers while maintaining incentives for carpools; and
- Express Toll Lanes (ETLs / ELs), which rely on full tolling and dynamic pricing to ensure reliable free-flow speeds.

These facilities share common operational goals, such as reducing congestion, enhancing travel-time reliability, and improving safety and exhibit similar design and management characteristics, such as being positioned on the leftmost portion of the facility and using buffer, delineator, or barrier-based separation, as well as relying on dynamic pricing and ATM integration (Abuzwidah & Abdel-Aty, 2024).

Accordingly, evaluating methodologies that focus exclusively on Express Lanes would be myopic, as HOV and HOT lane research has generated decades of empirical insights directly applicable to EL performance evaluation. Many foundational methodologies, including speed–flow analysis, travel time reliability metrics, safety performance functions, dynamic tolling evaluation, and before–after operational studies, were first developed in HOV-to-HOT conversion research and subsequently refined through managed-lane deployments across multiple states. Therefore, in this literature review, the research team considers methodologies applied across all Managed Lane types, ensuring a comprehensive and transferable framework for assessing Express Lanes and their impacts on adjacent General-Purpose Lanes (GPLs).

2.1 Methodological Framework

To comprehensively evaluate the operational, safety, and mobility impacts of the aforementioned facilities and their interactions with adjacent GPLs, prior research has employed a diverse set of methodological approaches. These approaches generally fall into three main categories:

- simulation and modeling,
- statistical and empirical analyses,
- and real-world applications.

Simulation- and modeling-based studies leverage analytical, macroscopic, mesoscopic, or microsimulation tools (e.g., CTM, DTA, VISSIM, Aimsun) to test alternative pricing, design, and control strategies under controlled experimental conditions. Statistical and empirical analyses rely on observed traffic, safety, environmental, or economic data to quantify facilities' performance,

identify causal relationships, and model behavioral responses. Real-world applications, including mainly government evaluations, operational monitoring reports, and corridor-level assessments, provide practical evidence on how Express Lanes perform once deployed, offering insights on implementation challenges, design constraints, and user responses.

2.1.1 Simulation and Modeling

The body of literature applying simulation and modeling to Express Lane evaluation is heavily dominated by tolling-oriented studies, particularly those focused on reactive, proactive, and dynamic toll optimization strategies. However, simulation frameworks have also been widely used to assess the impacts of facility design, operational policies, control strategies, and broader network behavioral responses. Within simulation-based research, microsimulation, especially using PTV VISSIM, clearly dominates, serving as the primary tool for analyzing lane-use dynamics, speed–flow relationships, access-point behavior, and pricing scenarios. Although less prevalent, macroscopic and Dynamic Traffic Assignment approaches do appear in the literature and are often employed for corridor-level pricing and reliability assessments. In parallel, a substantial category of work is associated with mathematical modeling and optimization, developing analytical formulations to study dynamic pricing, capacity management, system-delay minimization, and policy evaluation.

2.1.1.1 Tolling

Dynamic tolling strategies within managed lanes play a pivotal role in maintaining operational efficiency across freeway systems by influencing both tolled and adjacent GP lanes. These pricing mechanisms adjust tolls in real time or in anticipation of traffic conditions to manage demand, sustain target speeds, and enhance travel time reliability. Two distinct approaches have emerged in the literature, reactive and proactive tolling (Xie et al., 2024). Reactive strategies adjust tolls based on current traffic measurements, such as speed, flow, or occupancy, ensuring free-flow conditions through feedback control. In contrast, proactive strategies use predictive modeling and optimization to anticipate congestion and set tolls preemptively. The effectiveness of these mechanisms extends beyond the managed lanes themselves, as by regulating lane choice behavior, dynamic tolling directly impacts flow balance, congestion propagation, and travel time reliability on adjacent GP lanes, ultimately affecting corridor-wide mobility and efficiency.

i. Reactive Tolling Strategies

More specifically, reactive tolling strategies aim to adjust toll rates dynamically based on prevailing network conditions, such as traffic flow, speed, or occupancy levels. These strategies represent the state-of-the-practice in most managed lane systems, where tolls are continuously modified using real-time data to maintain desired performance targets (Lombardi et al., 2021). The fundamental objective is to ensure free-flow conditions on tolled lanes while optimizing corridor throughput and, in some cases, maximizing revenue.

Early work conducted by Yin & Lou (2009) proposed a feedback-control approach in which tolls are dynamically adjusted as a function of the difference between observed and target lane

occupancies measured by loop detectors. Simulation experiments demonstrated that this method could effectively sustain free-flow operations, improve throughput (veh/hr/ln), reduce queue formation, and increase revenue stability under varying demand conditions. Building on this concept, Lou et al. (2011) introduced a self-learning tolling algorithm that integrates a homogeneous demand model, based on users' value of time (VoT), with a multi-lane kinematic wave supply model. Their framework enables the system to learn travel behavior online and adjust tolls accordingly, with the objective of maximizing total corridor throughput and efficiently utilizing HOT lane capacities while differentiating performance between HOV and HOT users (e.g., vehicle-miles per lane, throughput balance).

In a real-world context, Cheng et al. (2014) applied a modified dynamic tolling approach to the I-95 Express Lanes in South Florida, focusing on a 7-mile southbound segment from Northwest 151st Street (Golden Glades Interchange) to FL-112. Using VISSIM microsimulation, the study incorporated travel time reliability (TTR), trip purpose, and user income levels to optimize tolls for both operational performance and revenue generation. Results showed that the modified algorithm produced steadier toll rate adjustments, higher overall revenue, and more frequent maintenance of speeds above 45 mph compared with the existing strategy. More recently, Pandey et al. (2020) advanced tolling control methods through a deep reinforcement learning (DRL) framework. In their model, the system state was defined by the number of vehicles within predefined network cells, while a deep neural network learned optimal tolling policies to balance multiple objectives, specifically minimizing total system travel time and maximizing toll revenue. This approach represents a shift from purely reactive mechanisms toward adaptive, learning-based toll management that dynamically responds to evolving traffic states.

ii. Proactive Tolling Strategies

While reactive tolling strategies rely solely on prevailing traffic conditions, proactive tolling approaches utilize forecasted network states or model-based optimization frameworks to determine toll rates in advance (Lombardi et al., 2021). These methods, though less common in current practice, have attracted increasing research interest due to their potential to preempt congestion, enhance travel time reliability, and improve overall system performance. Proactive tolling typically integrates traffic state prediction, optimization, and control theory to anticipate conditions before they deteriorate, rather than merely responding after congestion forms.

Dong et al. (2011) conducted one of the earliest comparative studies between reactive and proactive tolling approaches, evaluating their ability to maintain desired traffic density and prevent flow breakdowns along a freeway corridor. Their findings demonstrated that the proactive strategy, by anticipating congestion formation and adjusting tolls in advance, achieved superior performance in maintaining target levels of service (LOS) and avoiding traffic breakdowns on tolled links. Expanding this concept to large-scale systems, Zhang et al. (2019) formulated toll pricing as an optimization problem aiming to maximize toll revenue while adhering to network performance constraints and regulatory requirements. Their methodology was applied to the North Tarrant Express (NTE) TEXpress network, a 13-mile managed corridor encompassing I-820 and

TX-183 in Texas. The results highlighted that proactive optimization enabled more stable toll rate trajectories, greater revenue generation, and improved flow conditions on both managed and general-purpose lanes compared to static or purely reactive schemes.

From a methodological standpoint, Lentzakis et al. (2020) proposed a feature-variant hierarchical density-based clustering approach to define spatially adaptive tolling zones for distance-based pricing schemes. By clustering roadway segments based on dynamic traffic and spatial characteristics, the study demonstrated that well-calibrated proactive tolling zone configurations could significantly enhance overall network efficiency and equity compared to uniform or arbitrary distance-based schemes. More recently, Xie et al. (2024) advanced the field through a personalized dynamic tolling system driven by real-time traffic prediction and system optimization. The framework integrates simulation-based dynamic traffic assignment (DTA) with a multi-objective optimization problem that accounts for operator revenue, managed lane usage, traveler benefits, and equity. Closed-loop simulations using real operational data demonstrated that the predictive tolling system outperformed existing reactive policies, achieving higher toll revenues, more balanced lane utilization, and reduced corridor-wide congestion, while offering flexibility through policy hyperparameters tailored to different stakeholder priorities. Table 1 summarizes the reactive and proactive tolling strategies discussed above.

Table 1. Tolling Strategies in Managed Lanes: Reactive vs. Proactive

Category	Authors (Year)	Methodology / Model	Control Objective	Key Findings
Reactive	Yin & Lou (2009)	Feedback control: toll = f(observed occupancy − target)	Maintain target occupancy / free-flow; stabilize ops	Improved throughput (veh/hr/ln)
Reactive (adaptive)	Lou et al. (2011)	Self-learning tolling; online VoT learning + kinematic-wave	Maximize corridor throughput; preserve free-flow	Better HOT throughput;
Reactive (field-calibrated)	Cheng et al. (2014)	VISSIM microsim + modified dynamic tolls with TTR, income, trip purpose	Maintain ≥45 mph; steady tolls; maximize revenue w/ LOS constraint	Smoother toll profiles, higher revenue, speeds ≥45 mph more often than existing policy
Reactive (learning)	Pandey et al. (2020)	Deep RL (state = vehicles per cell); policy learns tolls	Multi-objective: minimize system TTT & maximize revenue	Improved corridor delay and revenue vs. fixed/reactive rules
Proactive	Dong et al. (2011)	Predict-then-control to keep density below breakdown	Maintain LOS; avoid breakdown	Proactive outperforms reactive in sustaining LOS and preventing breakdown on tolled links
Proactive (optimization)	Zhang et al. (2019)	Revenue-maximizing toll optimization w/ network & regulatory constraints	Maximize revenue subject to ops constraints	More stable tolls, higher revenue, improved ML & GP flow vs. static/reactive

Table 1. Tolling Strategies in Managed Lanes: Reactive vs. Proactive (continued)

Category	Authors (Year)	Methodology / Model	Control Objective	Key Findings
Proactive (zoning design)	Lentzakis et al. (2020)	Feature-variant hierarchical clustering → toll zones	Define spatially adaptive zones to improve performance/equity	Better network efficiency vs. uniform zones; supports distance-based, proactive schemes
Proactive (personalized pricing)	Xie et al. (2024)	Predictive DTA + system optimization; personalized/discount controls	Multi-component: revenue, ML usage, traveler benefit, equity	Beats existing policy on revenue, usage, reliability, and reduces congestion

iii. Dynamic Toll Optimization

Two primary operational objectives are consistently identified in the literature regarding High-Occupancy Toll (HOT) and Express Lanes: (i) maintaining free-flow conditions to ensure travel time reliability, and (ii) maximizing tolled lane throughput to minimize total system delay. Most dynamic toll-pricing methodologies developed over the past two decades pursue one or both of these objectives through a mix of reactive, proactive, or hybrid control frameworks.

Several studies have focused on throughput maximization as a primary design objective. Yin & Lou (2009) proposed a model-based dynamic pricing algorithm designed to adjust toll rates in real time to maximize HOT lane throughput while maintaining an acceptable level of service. Their framework integrates both reactive and proactive components to achieve rapid responsiveness and stable flow conditions. Extending this work, Lou et al. (2011) developed a multi-objective optimization model aiming to maximize throughput in each freeway segment while keeping HOT lane density below the critical threshold. Although the formulation placed less weight on maximizing flow, the resulting optimal densities remained close to critical density, conditions that can risk instability, particularly near HOT access points where shockwaves may propagate. Later, Pandey & Boyles (2018) further explored the determination of optimal dynamic tolls for managed-lane networks with multiple entry and exit points, accounting for spatial and temporal variations in demand. More recently, Xie et al. (2024) proposed a personalized, real-time prediction-based tolling system using an online bi-level formulation to jointly optimize displayed tolls and user-specific discounts. This framework improved both reliability and revenue while reducing system-wide delay, representing a modern hybridization of throughput-oriented and reliability-oriented control.

In contrast, other studies explicitly prioritized travel time reliability or social efficiency. Zhang et al. (2019) introduced a reliability-oriented dynamic pricing framework for HOT lanes, demonstrating that well-calibrated tolls can shift low-occupancy vehicles (LOVs) from general-purpose to HOT lanes, thereby improving travel times and network stability. Similarly, Jin et al. (2020) developed a dynamic pricing approach designed to maintain free-flow and maximize overall social efficiency even under conditions of limited knowledge about driver behavior or lane-choice parameters.

A third group of studies focused primarily on revenue optimization, where toll rates are determined to maximize net financial return under operational constraints. More specifically, Jang et al. (2014) presented a dynamic HOT pricing model that responds to real-time traffic conditions with an agency-oriented objective emphasizing toll revenue. Further exploring this concept, Song et al. (2015) expanded this framework by maximizing net social benefit, incorporating both toll revenue and user surplus to define an optimal toll rate that balances efficiency and equity. Table 2 summarizes the dynamic toll optimization objectives of these studies.

Table 2. Dynamic Toll Optimization Objectives for HOT/Express Lanes

Objective	Authors (Year)	Methodology	Optimization Focus	Key Findings
Throughput Maximization	Yin & Lou (2009)	Model-based feedback tolling with combined reactive & proactive components	Maximize HOT throughput while maintaining LOS	Dynamic tolls stabilize flow, maximize throughput (veh/hr/ln), and reduce queue formation under demand fluctuations
	Lou et al. (2011)	Multi-objective optimization (flow–density control)	Maintain density < critical; maximize section throughput	Optimal density near critical values increases efficiency but may cause instability near merge/diverge zones
	Pandey & Boyles (2018)	Dynamic toll optimization via simulation-based evaluation	Optimize tolls over multiple access points considering temporal demand	Optimal toll schedules reduce congestion propagation across entry–exit segments
	Xie et al. (2024)	Online bi-level optimization using predictive models & personalized discounts	Jointly optimize tolls + discounts to minimize delay & increase reliability	Improves reliability, equity, and revenue simultaneously; hybrid of throughput + reliability focus
Reliability & Stability	Zhang et al. (2019)	Reliability-oriented pricing model using field data	Maintain free-flow, reduce breakdown probability	Tolls shift low-occupancy vehicles (LOVs) to HOT, improving travel time reliability in both lane types

2.1.1.2 Facility Design and Access Considerations

The design and placement of access points, lane configurations, and separation treatments play a critical role in determining the operational efficiency and safety performance of Managed and Express Lane facilities. Several studies have examined how different geometric and operational design elements influence the interaction between MLs and adjacent GPLs, with particular focus on weaving maneuvers, buffer separation, and the "friction effect" that occurs when congestion in GPLs degrades ML performance.

At a macroscopic level, Liu et al. (2012) developed a Cell Transmission Model (CTM)-based framework that explicitly incorporates the friction effect, where congestion spillback in the GPLs negatively impacts ML speeds. This modeling approach enables sensitivity analysis for buffer-separated facilities and provides insight into capacity degradation mechanisms under varying access designs. At a more operational scale, Brewer (2014) analyzed ingress and egress maneuvers

at limited-access gates, evaluating driver behavior, entry/exit timing, and interaction patterns between ML and GPL traffic. Their findings emphasize the importance of strategically placed gates and sufficient merging/weaving distance to minimize turbulence and maintain stable flow conditions. Also, Sajjadi & Kondyli (2017) investigated access design and lane configuration impacts on the performance of SR-167 HOT lanes in Washington, combining VISSIM and macroscopic modeling. By analyzing one- and two-lane segments separated by flexible pylons (FPs), the study identified clear relationships between lane configuration, capacity, and speed–flow behavior.

Building on this perspective, Cai et al. (2018) used VISSIM microsimulation coupled with a driving simulator to assess the impact of weaving length near ML access points along I-95 in Miami. The study quantified how shorter weaving sections increase conflict rates and variability in safety surrogate measures (e.g., time-to-collision), underscoring the safety implications of access design. Similarly, Causseaux et al. (2020) developed an integrated methodology using Highway Capacity Software (HCS) and VISSIM to evaluate complex or multiple weaving segments that emerge from the placement of multiple EL access points. Their framework allows practitioners to test alternative access configurations and estimate capacity implications of overlapping weave segments, offering a decision-support tool for express lane project development. Table 3 summarizes the studies of facility design and access impacts discussed above.

Table 3. Facility Design and Access Impacts in Managed Lane Performance

Design & Access Element Studied	Authors (Year)	Modeling Tool / Approach	Key Findings
Buffer-separated MLs; interaction with congested GPLs	Liu et al. (2012)	CTM (macroscopic) with friction effect	Congestion in GPLs degrades ML speeds via friction; enables sensitivity testing of separation and access designs at corridor scale.
Ingress/egress maneuvers, gate placement, merge/weave spacing	Brewer (2014)	Operational analysis	Proper gate spacing and merge length reduce turbulence; improves stability in ML and adjacent GPLs.
Access design & lane configuration (1- vs 2-lane MLs; flexible pylons)	Sajjadi & Kondyli (2017)	VISSIM + macroscopic calibration	Clear capacity & speed–flow relationships by configuration; guidance for microsim calibration of ML–GPL interactions.
Weaving length near ML access; safety surrogates (e.g., TTC)	Cai et al. (2018)	VISSIM + driving simulator	Short weaving sections increase conflict rates and variability; longer weaving improves operations & safety.
Overlapping/complex weave segments from access placement	Causseaux et al. (2020)	HCS + VISSIM (integrated method)	Framework estimates capacity impacts of complex weaves; supports alternative screening for access placement.

2.1.1.3 Policy, Control, and Network Behavioral Studies

Beyond toll pricing mechanisms, a range of policy and operational control strategies, such as variable speed limits (VSL), ramp metering coordination, and minimum speed guarantees, have been explored in the literature to enhance traffic stability and ensure performance consistency within managed lane (ML) corridors.

Hegyi et al. (2005) applied a Model Predictive Control (MPC) framework for coordinated ramp metering across freeway corridors, achieving 20–30% reductions in total travel time through simulation. This methodology has since been adapted to integrate with ML operations, particularly to protect critical bottlenecks upstream of ingress and egress points, thereby improving corridor-wide performance. In a related control-oriented study, Toledo et al. (2015) introduced a real-time tolling controller that embeds minimum level-of-service (LOS) and speed constraints (e.g., ≥45 mph) directly into the optimization process. Although primarily focused on dynamic pricing, this formulation highlights the operational "minimum speed guarantee" concept often employed in High-Occupancy Toll (HOT) and Express Lane control algorithms to preserve reliability. Complementing these efforts, D. Frejo et al. (2019) developed a macroscopic modeling framework evaluating Variable Speed Limit (VSL) control strategies on freeway corridors. Their findings demonstrate that VSL implementation can effectively stabilize flow, reduce total travel time (TTS), and mitigate breakdown propagation, showing clear applicability to ML corridors when coordinated with adjacent GP lanes.

From a behavioral standpoint, Hasan et al. (2002) employed the MITSIM microscopic simulation platform to analyze spillback and diversion dynamics under varying demand and control policies. Their study quantified how spillback handling strategies and local demand conditions influence route diversion and mainline congestion, offering insights particularly relevant for ML corridors with access points near ramps or interchanges. Similarly, Pandey & Boyles (2019) developed and tested discrete-choice lane-selection models (binary logit and its variants) that incorporate toll and travel time differentials across ML and GP lanes. Their results confirm the significance of Value-of-Time (VOT)-segmented user classes in explaining ML utilization patterns and system efficiency. Table 4 summarizes these policy-control and behavioral modeling studies.

Table 4. Policy Control and Behavioral Modeling Studies in Managed Lane Operations

Policy or Behavioral Element	Authors (Year)	Modeling / Analytical Tool	Key Findings
Variable Speed Limits (VSL) coordination with GP lanes	D. Frejo et al. (2019)	Macroscopic flow modeling	VSL control stabilizes flow, reduces total travel time (TTS), and prevents congestion spillover between ML and GPL.
Minimum speed/LOS constraints (≥45 mph) embedded in pricing	Toledo et al. (2015)	Optimization-based real-time controller	Illustrates "minimum speed guarantee" policy; ensures reliability while adjusting tolls dynamically.
Coordinated ramp metering with ML ingress/egress	Hegyi et al. (2005)	Model Predictive Control (MPC) simulation	Simulation achieved 20–30% reduction in TTS; effective at mitigating congestion near ML ramps.

Table 4. Policy Control and Behavioral Modeling Studies in Managed Lane Operations (continued)

Policy or Behavioral Element	Authors (Year)	Modeling / Analytical Tool	Key Findings
Lane-choice modeling by Value of Time (VOT)	Pandey & Boyles (2019)	Discrete-choice modeling (Binary Logit, Multinomial Logit)	Travelers' VOT strongly influences ML usage; supports user-class segmentation for predictive tolling.
Spillback handling policies & route diversion	Hasan et al. (2002)	MITSIM microscopic simulation	Quantified impact of spillback and ramp interaction on diversion and corridor performance under varying demand.

Modeling approaches used to evaluate Express Lanes (ELs) generally fall into four categories, microscopic, mesoscopic, macroscopic, and optimization-based frameworks, each differing in resolution, computational demand, and analytical purpose. Microscopic simulation, most commonly implemented through tools such as VISSIM, represents individual vehicle movements and lane-changing decisions in high detail, making it the dominant method for studying EL access design, breakdown behavior, friction effects, and speed–flow relationships. Mesoscopic models offer a balance between behavioral detail and computational efficiency, while macroscopic models describe traffic using aggregate flow relationships, making them suitable for corridor-level reliability or pricing studies (D. Frejo et al., 2019). In parallel, optimization approaches, including dynamic tolling algorithms, reinforcement learning, mixed-integer optimization, and multi-objective formulations, have become increasingly prominent, particularly for pricing strategies and lane-use management. Overall, the literature is heavily concentrated in two dominant methodological streams: microscopic simulation for operational analyses, and optimization-based methods for toll-setting, control strategies, and system-wide performance evaluation.

2.1.1.4 Micro-simulation

Microsimulation and hybrid modeling approaches have been extensively utilized to evaluate the operational, safety, and environmental performance of ML and GP lane facilities. These studies offer critical insights into how lane configuration, vehicle behavior, and control strategies influence mobility and safety outcomes across different expressway contexts.

Ben-Akiva et al. (2003) developed one of the earliest microsimulation frameworks, known as *MITSIMLab*, which enables detailed evaluation of freeway traffic control strategies often paired with managed lanes. Their work established a foundational platform for modeling driver response, lane-changing dynamics, and control interventions under varying congestion and pricing conditions. Building upon such frameworks, Caltrans (2009) conducted a series of VISSIM-based analyses for managed lane corridors in Los Angeles and Orange County, focusing on HOT lane driver behavior calibration and access preference modeling. These efforts contributed standardized behavior parameters that can be directly applied to express and GP lane assessments.

A key advancement in linking operational and environmental models was introduced by Xu et al. (2016), who developed an automated interface between VISSIM and the U.S. EPA's MOVES

model. This integration allows researchers to assess the emission impacts of operational changes between express and general-purpose lanes, offering a framework for sustainability-focused evaluations. In a similar operational context, Sajjadi & Kondyli (2017) employed VISSIM to analyze SR-167 HOT lanes in Washington State and comparable segments in South Florida, focusing on capacity and speed–flow relationships under varying configurations of one-lane and two-lane facilities separated by flexible pylons. Abdel-Aty et al. (2020) used VISSIM to evaluate optimal Connected Vehicle (CV) lane configurations under varying market penetration rates and traffic conditions. The analysis incorporated safety (conflict frequency) and operational (speed, delay) metrics, identifying lane configuration strategies that improve both safety and mobility outcomes during peak and off-peak hours.

Guo et al. (2020) extended microsimulation research to mixed traffic and automated environments, assessing managed lane reliability and GP lane spillover effects using VISSIM. Their comparison of mixed-traffic, cooperative adaptive cruise control (CACC), and dedicated CACC lane scenarios demonstrated the system-level reliability improvements associated with automation-supportive ML designs. Similarly, Ma et al. (2021) applied VISSIM to evaluate Active Traffic Management (ATM) strategies, including Variable Speed Limits (VSL) and Ramp Metering (RM), on SR-408 in Orlando, Florida. The study showed that coordinated VSL–RM strategies significantly reduced crash risk and congestion propagation, underlining the effectiveness of co-deployed control mechanisms in expressway corridors with managed lanes. Expanding the operational dimension, Wei et al. (2023) evaluated contraflow HOV/managed lane designs along the I-215 corridor using VISSIM microsimulation. Results indicated that contraflow operations reduced average peak-hour delay by 76%, proving the operational benefits of reversible or directionally managed express facilities.

More recently, Naseri et al. (2024) utilized Aimsun microsimulation to analyze high-occupancy lane operations, offering before-and-after comparisons that revealed significant throughput gains and delay reductions on both managed and general-purpose lanes. Finally, Schönhofer et al. (2024) performed Aimsun-based feasibility and performance analyses of HOT lane scenarios, comparing lane choice, travel-time reliability, and environmental impacts relative to GP lanes. Their results support the use of integrated macroscopic–microscopic modeling frameworks for strategic evaluation of managed lane implementation. Table 5 summarizes these microsimulation-based studies.

Table 5. Microsimulation-Based Studies Evaluating Express and General-Purpose Lane Performance

Software	Authors (Year)	Study Context	Focus Area	Key Findings
MITSIMLab	Ben-Akiva et al. (2003)	Generic freeway corridor	Framework for microscopic evaluation of control strategies linked to managed lanes	Introduced a microsimulation platform capturing lane-changing and driver response; foundational for ML–GP integration modeling.
VISSIM	Caltrans (2014, 2019)	Los Angeles / Orange County corridors	HOT lane driver behavior calibration and access modeling	Developed behavioral calibration models and access preference parameters applicable to HOT–GP performance evaluation.
	Xu et al. (2016)	Expressway operational–environmental linkage (MOVES)	Integrated traffic–emission analysis	Automated VISSIM–MOVES linkage for evaluating emission changes due to operational improvements in ML vs. GP lanes.
	Sajjadi & Kondyli (2017)	SR-167 HOT (WA) & South Florida	ML–GP interactions, lane separation, and design	Found a 7.6% capacity drop for one-lane MLs with flexible pylons, stable flow in two-lane designs; informed speed–flow calibration.
	Abdel-Aty et al. (2020)	Controlled CV lane simulation	Connected Vehicle lane configuration (MPR sensitivity)	Evaluated safety (conflict frequency) and operational (speed, delay) metrics; identified optimal lane strategies by MPR.
	Guo et al. (2020)	Arterial and freeway ML networks	Managed lane reliability and CACC scenarios	Compared mixed, restricted, and dedicated CACC lanes; found improved stability and reliability under dedicated designs.
	Ma et al. (2021)	SR-408, Orlando (FL)	VSL + Ramp Metering (ATM) bundle analysis	Coordinated VSL–RM reduced congestion and crash risk; verified ATM as co-control for ML corridors.
	Wei et al. (2023)	I-215 corridor	Contraflow HOV/ML operations	Contraflow design reduced peak-hour delay by 76% vs. baseline; improved corridor throughput.
Aimsun	Naseri et al. (2024)	HOV → HOT/EL conversion	Before–after performance assessment	Documented significant throughput and delay reductions in both ML and GP lanes.
	Schönhofer et al. (2024)	HOT feasibility and performance analysis	Lane choice, travel-time reliability, environmental metrics	Found improved mode choice, reliability, and emission outcomes vs. GP baseline.

However, besides the microsimulation approaches, a wide range of modeling frameworks have been employed to analyze the operational and behavioral impacts of ELs and adjacent GP lanes. These approaches vary from network-level dynamic traffic assignment (DTA) to macroscopic system models and optimization-based control formulations, each offering unique capabilities for evaluating lane choice behavior, travel time reliability, and system-wide efficiency (Lombardi et al., 2021).

2.1.1.5 Dynamic Traffic Assignment (DTA) Approaches

DTA models enable the capture of time-dependent route and lane choice behaviors under congestion and pricing effects, making them ideal for evaluating network-level performance of Express Lane systems. Abdelghany et al. (2000) utilized the *DYNASMART* mesoscopic simulator to design and evaluate HOT lane configurations under varying separation treatments, access frequencies, and eligibility policies, which constitutes one of the earliest applications of DTA for managed lanes. Building on this foundation, (M. E. Ben-Akiva et al., 2012) enhanced the *DynaMIT-P* framework to analyze highly congested networks by integrating dynamic route choice, demand elasticity, and real-time supply calibration, thereby improving predictive accuracy for managed corridor studies. More recently, Zhang et al. (2019) implemented an online-calibrated DTA pricing model that dynamically adjusts supply parameters using surveillance data to manage lane choice and maintain travel time reliability on the NTE TEXpress corridor.

2.1.1.6 Macroscopic Frameworks

Macroscopic models have been widely adopted for corridor-level express lane analyses due to their computational efficiency and ability to represent flow dynamics through aggregate relationships. Lou et al. (2011) proposed a self-learning dynamic pricing framework using a macroscopic representation to maintain free-flow conditions on HOT lanes while comparing throughput and reliability outcomes between MLs and GPLs. Similarly, Pandey et al. (2020) applied a deep reinforcement learning approach integrated with a multi-class Cell Transmission Model (CTM) to optimize toll rates under system-delay and reliability objectives, providing an open-source benchmark for macroscopic-level dynamic pricing analysis.

2.1.1.7 Optimization-Based Models

Optimization approaches form the core of many tolling and control studies, balancing multiple objectives such as throughput maximization, delay minimization, and revenue generation. Jang et al. (2014) proposed a flexible multi-objective dynamic pricing model that can minimize delay, maximize revenue, or combine both objectives while maintaining target LOS constraints (e.g., ≥45 mph). Extending these principles, Toledo et al. (2015) developed a real-time simulation-based toll control system that dynamically adjusts tolls to optimize operator objectives while ensuring acceptable service levels across ELs and GP lanes. Pandey & Boyles (2018) formulated a bi-level optimization framework for corridors with multiple access points, accounting for realistic lane choice behavior and system-wide performance feedback. Similarly, Tan & Gao (2018) applied a

Hybrid Model Predictive Control (MPC) approach, formulating the pricing problem as a mixed-integer linear program (MILP) to maintain stability and desired LOS across multiple entry and exit points. More recently, Xie et al. (2024) developed a real-time personalized tolling framework integrating traffic prediction and optimization to enhance travel time reliability and operator revenue, with the capability to tune the system toward minimizing total delay. Table 6 summarizes these modeling approaches.

Table 6. Modeling approaches for express-lane evaluation (DTA, macroscopic, optimization)

Approach	Authors (Year)	Objective / focus	Key Findings
DTA	Abdelghany et al. (2000)	Evaluate ML configurations with time-dependent lane/route choice	DTA captures access frequency and separation effects on ML–GP performance
	Ben-Akiva et al. (2012)	Predictive corridor analysis with real-time supply calibration	Better lane/route choice realism; improved forecasts under pricing
	Zhang et al. (2019)	Reliability-oriented pricing; dynamic supply parameter updates	Stabilizes lane choice, improves reliability vs. static/reactive pricing
Macroscopic	Lou et al. (2011)	Maintain free-flow while maximizing throughput	Preserves reliability; clarifies ML vs GP throughput tradeoffs
	Pandey et al. (2020)	Minimize system delay; improve reliability	RL outperforms rule-based tolling; open-source benchmark
Optimization	Jang et al. (2014)	Min delay, max revenue, or weighted mix with LOS constraint (≥45 mph)	Flexible objectives can maintain LOS while meeting agency goals
	Toledo et al. (2015)	Operator objective with embedded LOS/speed constraints (real-time)	Keeps EL free-flow; smoother tolls; tracks GP spillover impacts
	Pandey & Boyles (2018)	Corridor performance with realistic lane choice (Bi-level)	Reduces congestion propagation; access-aware toll updates
	Tan & Gao (2018)	Stability and LOS control, online/offline	Feasible real-time control; improves GP outcomes via coordinated pricing
	Xie et al. (2024)	Revenue, usage, traveler benefit, equity; tune toward system delay (bi-level)	Improves revenue, reliability, and reduces congestion vs existing policy

2.1.2 Statistical and Empirical Analyses

A substantial portion of the Express Lane literature relies on statistical and empirical evaluation methods that examine real-world performance across safety, traffic operations, and environmental or economic outcomes. Safety-focused studies commonly employ crash databases, detector

records, and advanced statistical models, such as Empirical Bayes methods, Poisson/negative binomial regression, and machine-learning–based severity prediction, to quantify changes in crash frequency, severity, and spatial distribution resulting from EL implementation. Traffic operations research typically leverages large-scale speed, volume, and travel time datasets, often using performance measures like speed–flow relationships, buffer index, planning time index, and reliability-based metrics to compare EL and GPL performance under varying congestion levels. Beyond mobility outcomes, empirical analyses also explore environmental and economic impacts, incorporating emissions modeling (MOVES, etc.), fuel consumption estimation, stated-preference surveys, value-of-time inference, and benefit–cost evaluations.

2.1.2.1 Safety

Safety is a central consideration in evaluating the operational impacts of ELs on freeway systems. Empirical studies have increasingly focused on whether EL implementation affects overall crash risk, severity, and lane-level safety distribution between ELs and GPLs. A range of analytical frameworks, cross-sectional and before–after analyses, Safety Performance Functions (SPFs), and emerging machine-learning models, have been employed to quantify these effects.

Abuzwidah & Abdel-Aty (2024) conducted one of the most comprehensive Florida-based studies, analyzing 55 miles of EL corridors (including I-95) using cross-sectional and before–after designs enhanced by Empirical Bayes modeling. The study found that ELs exhibited improved safety performance, with crash modification factors consistently below one, while GPLs experienced marginal increases in crash frequencies, suggesting a redistribution rather than a net rise in total crashes. Earlier work by Abuzwidah et al. (2014) reached similar conclusions, confirming that converting HOV lanes to Express Lanes did not compromise overall freeway safety. At a methodological level, (Yuan et al., 2021) demonstrated that Safety Performance Functions can be effectively developed at varying spatial aggregation levels using microscopic detector data from California, Florida, and Virginia. Their results indicated that managed lanes, particularly HOV and HOT facilities, positively influenced crash frequency reduction. Rim et al. (2023) advanced this approach by developing Poisson–Lognormal SPFs for freeway weaving segments in Florida, Kansas, and Michigan. Their analysis highlighted that traffic conditions and vehicle interactions in weaving areas are key contributors to crash risk.

Recent efforts have incorporated advanced machine-learning techniques to address sparse data and dynamic traffic conditions on newly implemented facilities. Kitali et al. (2021) applied a Support Vector Machine (SVM) model trained using a Firefly Algorithm to crash data from four California EL facilities. The analysis revealed that crash severity increased under conditions involving concrete barriers, high traffic volumes, mountainous terrain, weekends, adverse surface conditions, and nighttime operation, whereas wider shoulders mitigated risk. These findings emphasize the importance of geometric design and roadway context in maintaining EL safety. Also, Yang et al. (2025) developed a hybrid deep-learning framework integrating Convolutional Neural Networks (CNN) and Long Short-Term Memory (LSTM) models to predict crash likelihood in influence areas of Florida's I-4 Express. This approach enabled early-stage safety monitoring where

traditional crash frequency models were infeasible. Similarly, Faden et al. (2025) examined the safety interdependencies between ELs and GPLs on the I-4 Ultimate corridor. Using a Poisson–Lognormal–Lindley model to manage excess zeros and a copula-based framework to assess dependence between lane types, the study found higher crash risk near merge segments and in rightmost EL lanes with elevated occupancy, reinforcing the operational link between lane usage and safety exposure. Table 7 summarizes the safety-oriented statistical and empirical analyses.

Table 7. Statistical/Empirical analyses for express-lane evaluation: safety

Authors / Year	**Study Focus & Location**	**Methodology / Data**	**Key Findings**
Abuzwidah et al. (2014)	Safety impact of EL implementation and HOV-to-EL conversions across 55 miles of Florida corridors	Cross-sectional and Before–After methods with Comparison Group and empirical Bayes approach	Converting or adding ELs did not compromise freeway safety; crash modification factors below 1 for ELs; marginal redistribution of crashes to GPLs.
Kitali et al. (2021)	Injury severity factors on EL facilities (California, 61 miles, 2012–2014)	Support Vector Machine (SVM)	Injury/fatality risk increased with concrete barriers, high AADT, rolling terrain, weekends, adverse conditions, and nighttime; wider shoulders reduced severity.
Yuan et al. (2021)	Development of Safety Performance Functions (SPFs) for managed lanes (CA, FL, VA)	negative binomial regression using microscopic detector data	Demonstrated feasibility of SPFs using lane-level detector data; managed lanes (HOV/HOT) showed positive safety effects across aggregation levels.
Rim et al. (2023)	Crash frequency modeling for freeway weaving segments (FL, KS, MI)	Poisson Lognormal (PLN) regression with Akaike Information Criterion (AIC) variable selection	Weaving traffic conditions and geometric design significantly influence crash frequency; weaving intensity at EL access points is critical.
Abuzwidah & Abdel-Aty (2024)	Safety performance of Florida ELs (I-95 and others)	Cross-sectional and Before–After analysis with Empirical Bayes estimation	Express Lanes exhibited improved safety; GPLs showed slight increases, suggesting crash redistribution
Yang et al. (2024)	Crash prediction near I-4 Express Managed Lanes (Florida)	Deep Learning (CNN + LSTM) using MVDS detector data and anomaly detection learning (ADL)	ADL model accurately predicted crash likelihood in low-crash EL environments
Faden et al. (2025)	Safety interaction between ELs and GPLs, I-4 Ultimate Express Lanes (Florida)	Poisson Lognormal Lindley (PLN-L) model + Copula framework using microscopic detector data	Found dependency between GPL and EL crash frequencies; rightmost EL occupancy and merge segments increase crash likelihood

2.1.2.2 Traffic Operations: Speed, Volume, and Travel Time Reliability

Empirical studies examining ELs and adjacent GP lanes have primarily focused on lane-level operational metrics such as speed–flow behavior, volume interactions, and travel time reliability. These investigations employ field sensor data, statistical modeling, and comparative before–after analyses to quantify mobility improvements, frictional effects, and system-wide performance.

Thomson et al. (2012) conducted one of the earliest multi-state empirical investigations into traffic flow behavior across various managed-lane configurations. Using sensor data from multiple corridor types, the study derived speed–flow curves segmented by lane separation and number of lanes, accounting for frictional effects caused by slow vehicles or congestion spillback from adjacent GP lanes. The resulting relationships characterized how managed-lane performance degrades under mixed traffic or access restrictions, providing a reference framework for evaluating throughput and operational stability. Building on lane-interaction dynamics, Avelar et al. (2016) analyzed lane-level speed and volume data from the Houston managed-lane corridor using multivariate regression models. The findings revealed that performance in the leftmost GP lane exerts a significant influence on managed-lane speeds, confirming the existence of a friction effect between the two facilities. The study further demonstrated that the use of vertical pylons within buffer-separated lanes mitigates adverse GP-to-ML interference, highlighting the importance of physical separation in preserving speed reliability.

At the corridor level, Kadeha et al. (2020) examined travel time reliability for the I-95 Express Lanes in Miami. Using archived traffic data from the Regional Integrated Transportation Information System (RITIS), the study computed the Buffer Index (BI) to compare reliability between Express and GP lanes. Express Lanes consistently exhibited lower BI values, indicating superior reliability, while GP lanes also benefited from reduced variability when ELs were open. Also, Fu et al. (2023) expanded the empirical evaluation of managed freeways by modeling the relationship between volume differences and crash frequency across reversible and HOV corridors in Virginia, Arizona, and Washington. Although primarily safety-oriented, their results confirmed that speed differentials between managed and general-purpose lanes are positively associated with crash frequency, suggesting that operational imbalances can create secondary safety implications. Table 8 summarizes the traffic-mobility analyses.

Table 8. Statistical/Empirical analyses for express-lane evaluation: traffic mobility

Authors / Year	Facility / Location	Data & Methodology	Key Variables / Measures	Key Findings
Thomson et al. (2012)	Multi-state managed-lane facilities	Loop detector data; empirical curve fitting	Speed–flow relationships; frictional effects	Identified GP congestion and slow vehicles as major friction factors on ELs.
Avelar et al. (2016)	Houston Managed Lane corridor	Lane-level speed and volume data; multivariate regression	ML speed, GP lane volume, separator type	Leftmost GP lane volumes significantly influence ML speeds; vertical pylons mitigate cross-lane interference.
Kadeha et al. (2020)	I-95 Express, Miami (FL)	RITIS data; Welch's t-test comparison	Buffer Index (BI); Travel Time Index (TTI)	ELs achieved significantly lower BI (values → higher reliability); GP lanes' reliability improved when ELs were open.
Fu et al. (2023)	Reversible & HOV corridors in VA, AZ, WA	MVDS data; hierarchical & Poisson lognormal models	Volume difference (RL–GPL); speed difference	Larger speed and volume differences between ML and GP lanes correlated with increased crash frequency

2.1.2.3 Environmental and Economic Impacts

Beyond mobility and safety, a growing body of empirical research has sought to quantify the economic and environmental implications of EL operations. These studies typically combine observed field data, traveler preference surveys, econometric modeling, and simulation-based emissions analyses to assess how managed lanes influence user behavior, corridor efficiency, and sustainability outcomes.

From an economic perspective, several investigations have examined willingness to pay, benefit–cost ratios, and travel time valuation associated with EL use. Devarasetty et al. (2012) conducted a stated-preference survey on Houston's Katy Freeway to estimate the value of travel time savings (VTTS) under different experimental designs. Similarly, Casady et al. (2020) applied a simplified social benefit–cost analysis (BCA) across seven U.S. toll-managed lane projects to evaluate their overall efficiency. The analysis demonstrated that project benefit-cost ratios were strongly dependent on assumed VTTS levels, implying that conventional values often undervalue the benefits of an uncongested alternative such as Express Lanes. The authors concluded that the monetary worth of travel reliability and reduced congestion tends to be systematically underestimated in traditional BCAs. More recently, Lin et al. (2024) used a revealed-preference framework combining electronic-toll transponder data with probe-based travel times in Virginia to estimate travelers' willingness to pay before and after the COVID-19 pandemic. The study found that longer Express Lane segments generated higher user valuation and more consistent usage, while peak-period willingness to pay decreased post-pandemic, reflecting the flexibility of telecommuting and schedule changes.

Parallel to economic analyses, empirical evaluations have explored the environmental consequences of managed lane implementation. Javid et al. (2017) conducted a nationwide regression analysis relating HOV lane mileage and socioeconomic characteristics to carpooling rates across all U.S. states. Their results indicated that greater HOV lane availability and higher fuel prices were associated with increased carpooling propensity, leading to inferred reductions in carbon dioxide and criteria pollutant emissions. At the project level, Y. (Ann) Xu et al. (2017) examined the I-85 corridor in Atlanta, Georgia, following its conversion from HOV to HOT lanes. Using the U.S. EPA's MOVES model with detailed before-and-after vehicle activity data collected by the Georgia Department of Transportation, the authors discovered that, when controlling for fleet turnover by holding the calendar year constant, peak-hour mass emissions increased by up to 17%, though CO_2 levels remained relatively stable. This outcome emphasized the importance of consistent temporal calibration in emission assessments and cautioned against attributing emission reductions solely to lane conversion without accounting for vehicle technology changes. Complementing this work, Du et al. (2021) conducted a Houston-area case study comparing vehicle activity and emissions between managed and general-purpose lanes. Statistical analyses, including ANOVA tests, revealed that vehicles on managed lanes exhibited smoother driving profiles, fewer hard accelerations and higher average speeds, which increased per-vehicle emission rates (g/h) but reduced total corridor-level emissions by 32–43 percent owing to decreased congestion and fewer vehicles. Table 9 summarizes the economic and environmental analyses.

Table 9. Statistical/Empirical analyses for express-lane evaluation: economic & environmental

Focus Area	Authors / Year	Data & Methodology	Key Findings / Insights
Economic	Devarasetty et al. (2012)	Stated-preference survey using Bayesian (Db) efficient, mixed-logit estimation	VTTS estimates varied significantly across survey designs, highlighting design sensitivity in economic valuation of toll facilities.
	Casady et al. (2020)	Simplified BCA using project cost, benefit, and VTTS scenarios	Found that B/C ratios are highly dependent on VTTS assumptions; conventional VTTS likely undervalues the benefits of uncongested managed lanes.
	Lin et al. (2024)	econometric modeling (pre-/post-COVID)	Longer lanes had higher WTP and usage; peak period WTP declined after pandemic due to schedule flexibility; economic benefits depend on asset length and demand conditions.

Table 9. Statistical/Empirical analyses for express-lane evaluation: economic & environmental (continued)

Focus Area	Authors / Year	Data & Methodology	Key Findings / Insights
Environmental	Javid et al. (2017)	Cross-sectional regression models	More HOV lane mileage and higher fuel prices correlate with greater carpooling rates and lower estimated emissions nationwide.
	Xu et al. (2017)	Before–after MOVES model analysis	When calendar year held constant, peak-hour mass emissions increased; fleet turnover must be controlled for accurate impact attribution.
	Du et al. (2021)	ANOVA statistical tests on micro-driving and emission rates	Managed-lane vehicles showed smoother trajectories and higher speeds (increased g/h rates), but corridor-level NOx and HC emissions were lower than GPL;

2.1.3 Real-world Application

A broad range of federal and state transportation agencies have examined the operational, economic, and freight implications of managed and express lanes. Collectively, these reports provide a practical foundation for understanding how express lane strategies interact with general-purpose lanes and broader corridor performance.

The Texas Department of Transportation (TxDOT) was among the earliest agencies to investigate performance monitoring and evaluation frameworks for managed lanes. The TxDOT (2005) study identified best practices for measuring operational outcomes and emphasized that freight-focused managed lane facilities, including truck-only or mixed-flow bypass lanes, prioritize pavement preservation and safety over direct travel-time savings. It further noted that toll revenue potential from freight-exclusive facilities is limited, highlighting the need for integrated freight mobility planning rather than standalone freight lanes. Building upon behavioral analysis, Caltrans (2009) developed a new HOV driver behavioral model incorporating access preference and acceptable gap selection for buffer-separated lanes. The model was validated on SR-57 in Orange County, California, through simulation testing, revealing improved representation of weaving and merging maneuvers between express and general-purpose lanes under varying traffic conditions.

Subsequent (TxDOT, 2010) studies expanded this operational focus to freight behavior. One examined truck responses to road pricing in Central Texas, finding that willingness to pay tolls varied widely by commodity type, trip length, and delivery deadlines. Time savings remained the most cited benefit of toll usage, whereas limited toll availability and high costs were the primary deterrents. Another TxDOT report on geometric design and operational factors influencing truck use of toll roads identified specific design recommendations, such as adding climbing lanes, minimizing long downgrades, and improving signage, to make toll roads more attractive for truck

operators (TxDOT & FHWA, 2010). The study concluded that improved design and connectivity could enhance both safety and reliability for freight operators within managed lane systems.

Parallel efforts by WSDOT (2011) assessed the feasibility and impacts of tolling the I-5 reversible express facility in Seattle. This planning-level analysis considered potential toll revenues, economic effects, and traffic diversion impacts without identifying specific revenue uses, illustrating early recognition of cross-lane interactions when modifying existing express facilities. Also, in Florida, the 95 Express Lessons Learned Report (FDOT, 2012) offered direct insights from real-world implementation. The study addressed challenges in driver perception of tolling and information signage, leading to modifications such as removing confusing toll gantries and emphasizing dynamic messaging about congestion rather than price. FDOT also proposed revisions to the tolling rule to allow market-driven pricing, which constitutes an early example of adaptive toll management aimed at improving system efficiency for both express and general-purpose lanes. Complementing these state-level findings, the U.S. Department of Transportation (USDOT, 2012) published a study on congestion pricing and its role in regional transportation planning. The report underscored congestion pricing's potential to enhance economic competitiveness and freight mobility by improving travel time reliability and reducing congestion-related costs. It also acknowledged that many freight carriers remain skeptical of direct congestion reduction benefits, reinforcing the need for improved analytical modeling and clearer demonstration of freight advantages in pricing programs.

Later on, the Florida Department of Transportation (FDOT, 2014) developed one of the earliest structured frameworks for assessing EL performance in its *Express Lanes Reliability Measures* report. As Florida expanded its express facilities, particularly along the I-95 corridor, FDOT highlighted the need to standardize performance monitoring. The study recommended travel time and speed as the primary performance measures, emphasizing that reliability should be tracked through volume-weighted travel times for both ELs and GP lanes. A key operational benchmark was established: maintaining at least 45 mph for 90% of peak-period travel, consistent with Federal Highway Administration (FHWA) guidelines. Similarly, the U.S. Department of Transportation (USDOT, 2014) conducted a two-stage panel survey involving approximately 1,600 households to assess behavioral impacts of a federally sponsored variable tolling program on Atlanta's I-85 corridor. The findings revealed that solo drivers accounted for 82% of Express Lane trips, while vehicle occupancy among carpoolers declined as many shifted to GP lanes. Interestingly, the opposite trend was observed on GP lanes, where average occupancy increased, demonstrating complex inter-lane behavioral redistribution in response to toll pricing. Also, The Minnesota Department of Transportation (MnDOT, 2014) examined the *Effect of MnPASS Lane Design on Mobility and Safety* by comparing two distinct corridor configurations: the closed-access design on I-394 and the open-access configuration on I-35W. Using detailed video-based traffic observations, MnDOT documented that restricted access improved lane discipline and reduced turbulence, while open-access designs encouraged greater flexibility but occasionally led to operational friction between EL and GP lanes. These insights informed future lane-access

management strategies for dynamically priced facilities. At the same time, the Utah Department of Transportation (UDOT, 2014) evaluated how toll rates, occupancy requirements, and enforcement levels influenced EL usage under various congestion and pricing scenarios. The agency concluded that simply raising toll rates within existing caps would not be effective in improving speeds without adjusting maximum toll limits and revising high-occupancy vehicle (HOV) eligibility from 2+ to 3+ persons during peak hours. These recommendations marked an early recognition of price elasticity and equity trade-offs within toll-managed operations.

Further extending federal insight, the U.S. DOT's Congestion Reduction Demonstration (CRD) Program included the Atlanta CRD Evaluation (USDOT & FHWA, 2014), a national initiative assessing HOV-to-HOT lane conversions and complementary transit investments. The Atlanta case examined the conversion of 16 miles of I-85 lanes into Express Lanes and incorporated new park-and-ride facilities. The evaluation included a *Goods Movement* component, where freight operators reported perceiving net benefits from tolling when time savings outweighed higher operating costs. Approximately half of surveyed carriers stated that improved reliability justified the toll expense, highlighting freight's adaptive response to managed lane environments. In its 2015 follow-up, USDOT (2015) reported that tolling increased the effective corridor capacity by improving flow efficiency and throughput, particularly person throughput during peak hours. Although some regions experienced increased vehicle miles traveled (VMT) and related emissions, partly due to reduced carpooling and regional economic growth, the net effect was reduced congestion delay and improved overall corridor performance. Complementary to this, the UDOT (2015) analyzed speed–flow relationships on its Express Lane facilities, estimating how policy interventions such as enhanced enforcement, higher peak-period tolls, and public education campaigns would affect performance. Results indicated that a combination of these strategies could increase EL travel speeds by up to 7.8 mph under optimal conditions, reinforcing the role of operational management alongside pricing adjustments. While, the "Urban Partnership Agreement" (UPA) synthesis report (USDOT, 2015) summarized outcomes from six demonstration sites: Atlanta, Los Angeles, Miami, Minneapolis, San Francisco, and Seattle. Each location applied a holistic congestion management strategy known as the "4Ts" framework—tolling, transit enhancement, telecommuting/TDM, and technology deployment. Across these corridors, tolling was shown to increase travel speed reliability and throughput, while integrated multimodal improvements enhanced regional accessibility and system resilience.

Later on, the FHWA (2016) observed that many of the most successful managed lane programs in the United States integrate tolling within broader freeway management and multimodal strategies, combining transit expansion, carpooling incentives, and demand management approaches. However, public acceptance remained a consistent challenge. The report noted that equity concerns, particularly perceptions that tolling disproportionately impacts lower-income drivers, were among the largest barriers to widespread acceptance of congestion pricing. This finding reinforced the importance of transparent communication and reinvestment of toll revenues into accessible mobility alternatives.

In Florida, the Tampa Bay Express (TBX) Planning-Level Traffic and Revenue Study (FDOT, 2017) advanced technical methods for express lane forecasting and performance evaluation. The study implemented a two-phase Traffic and Revenue (T&R) analysis combining Bluetooth-based origin–destination (O-D) data and stated preference (SP) survey results to refine gross revenue forecasts and evaluate user behavior. Through the use of a queue accumulator tool, the study refined assumptions on bottlenecks and queuing dynamics by scenario and year, pioneering data-driven techniques for modeling express lane reliability and revenue in congested corridors. Also, the Mercator Advisors LLC & Caltrans (2017) policy review provided a governance and public engagement perspective, focusing on how express lane implementation interacts with contractual provisions under California's Public-Private Partnership (P3) framework. Although the report primarily addressed legal and policy issues surrounding public perception and agency accountability, it acknowledged a gap in evaluating intermodal and freight connectivity, noting that such impacts were not yet systematically analyzed in California's express lane policy environment. In addition, in Los Angeles (LA Metro, 2018), the Metro Board considered revisions to its vanpool and high-occupancy vehicle (HOV) exemption policies on the I-10 ELs. A white paper explored alternative scenarios for toll exemptions, including maintaining toll-free eligibility for vehicles with five or more occupants (HOV5+) while removing free access for smaller carpools. Comparative analysis across several U.S. express toll lane (ETL) facilities revealed that most agencies offered partial toll exemptions to registered vanpools, though the eligibility criteria varied widely. The study recommended adoption of the HOV5+ exemption policy as a balanced approach to encourage higher vehicle occupancy while maintaining toll revenue stability. At the federal level, the USDOT (2018) documented the broader synergistic benefits of pricing and transit coordination. The report highlighted that express buses operating on tolled expressways, such as those in the I-95 Express network in South Florida, achieved significant travel time reductions and improved schedule reliability. The expansion of 22 new articulated buses and 10 new express routes between Broward County and Downtown Miami illustrated how express lanes can effectively support transit efficiency and mode shift when combined with dynamic tolling.

The WSDOT (2019) published a comprehensive data analyses report covering 45 months of I-405 Express Toll Lane operations, providing one of the most robust longitudinal evaluations of EL performance in the U.S. The report found that the I-405 ETLs continued to meet all three agency goals: providing user choice, offering faster and more reliable travel, and generating reinvestment revenue. Specifically, drivers saved an average of 11 minutes per trip using the ETLs, while corridor throughput increased by up to 23% during peak hours. Approximately 67% of all travelers opted to pay a toll, with the remainder qualifying for toll-free access, demonstrating sustained market viability and reliability improvements relative to the pre-tolling period. Similarly, the NCHRP (2020) synthesized input from multiple state DOTs to assess the institutional and communication challenges associated with priced managed lane implementation. Across six study sites, including Florida's I-95 Express, surveyed agencies reported that public understanding of managed lane objectives remained limited, leading to difficulties in messaging the balance between congestion relief, equity, and revenue goals. FDOT's subsequent driver education

campaigns were cited as best practices in clarifying pricing rationale and improving acceptance. Similarly, following up this research, the Washington State Transportation Commission (2021) conducted the *Low-Income Toll Program Study* for the I-405 and SR-167 Express Toll Lanes, exploring options for expanding toll affordability and access equity. A national scan of tolling agencies revealed that low-income drivers face diverse barriers, including lack of digital payment access and complex enrollment processes. The study concluded that low-income toll discount programs could expand equitable mobility access, particularly when linked to broader transit and ridesharing incentives.

The Florida Department of Transportation conducted one of the most comprehensive empirical evaluations to date on the safety performance of managed lanes with different separation treatments (FDOT, 2022a). Using data from 95 Express and 595 Express facilities in Florida, alongside seven comparable facilities in Texas and one in Georgia—the study developed Safety Performance Functions (SPFs), Crash Modification Factors (CMFs), and severity distribution functions for distinct crash severities and collision types. The analysis differentiated between non-reversible and reversible managed lane configurations, examining separation by tubular delineators (pylons) and concrete barriers. Findings revealed that for non-reversible lanes, fatal and injury (FI) as well as property damage only (PDO) crashes tended to decrease with greater separation width in the presence of pylons, while multi-vehicle crashes increased slightly with each additional managed lane. These results established an important empirical foundation for data-driven geometric design and safety-based lane configuration policies. At the federal level, the USDOT and North Carolina DOT (Pandey et al., 2022) introduced a simulation-based reinforcement learning framework for optimizing dynamic tolls. This study provided one of the first demonstrations of how AI-driven toll control can address equity-related delay differentials across travel groups. Results indicated that higher toll rates and greater demand tend to exacerbate delay inequities, whereas discount structures linked to travelers' value of time (VoT) can effectively mitigate disparities in experienced delay. By explicitly modeling user heterogeneity, this work bridged the gap between operational efficiency and social equity in congestion pricing research.

The Colorado Department of Transportation, through its High-Performance Transportation Enterprise (HPTE), now operating as the Colorado Transportation Investment Office (CTIO), released its annual report highlighting advances in project delivery, toll operations, and corridor performance monitoring (CDOT, 2023). This report emphasized the institutional evolution toward more agile public-private partnership (P3) governance structures, with a focus on sustaining revenue reinvestment while maintaining user reliability in managed corridor systems. Later on, the USDOT (2023) further reinforced the national significance of managed lanes within broader highway operations policy. Its annual program summary incorporated discussion on managed lane and freight interactions, underscoring how express lane development can influence freight reliability and GPL performance.

Finally, the Federal Highway Administration published a comprehensive national inventory of specialty lanes across all 50 U.S. states and Puerto Rico (FHWA, 2024). This report documented the widespread transition of HOV facilities into HOT and Express Toll Lane (ETL) configurations. The report identified 49 HOT and ETL facilities operating dynamic pricing systems, highlighting their growing role in mitigating congestion and generating reinvestment revenue. The inventory also noted that a minority of states, such as Arizona, Tennessee, Michigan, Connecticut, and Nevada, continue to operate only traditional HOV facilities without adopting toll-based pricing. This large-scale documentation provides a national baseline for operational benchmarking, enabling states to compare managed lane practices and policy outcomes within a unified analytical framework.

Together, these reports signify a continued institutional evolution in managed lane policy, where data-driven safety assessment, machine learning-based toll optimization, and national standardization efforts are shaping the next generation of express lane planning. The integration of equity-aware control mechanisms, freight considerations, and adaptive design practices reflects a clear trajectory toward holistic, performance-optimized, and socially balanced managed lane systems. Table 10 summarizes the key government and agency reports reviewed.

Table 10. Summary of Key Government and Agency Reports

Agency / Year	Focus	Methodology / Data Sources	Key Findings & Insights
TxDOT (2005)	Performance Monitoring and Evaluation Practices	Review of managed lane practices, stakeholder interviews	Identified best evaluation frameworks; freight-focused lanes prioritize pavement preservation & safety over time savings; limited toll revenue potential from freight-exclusive facilities.
Caltrans (2009)	Development of a New HOV Driver Behavioral Model	Simulation and behavioral modeling of weaving/merging in buffer-separated HOV lanes	Developed model incorporating access choice and acceptable gaps; better captured driver lane-change behavior under varying traffic conditions.
TxDOT (2010)	Responses of Trucking Operations to Road Pricing	Carrier surveys & industry segmentation (commodity, trip distance, delivery windows)	Identified heterogeneity in toll-road use; time savings main benefit; toll cost & availability main barriers; highlighted need for freight-sensitive toll policy.
TxDOT & FHWA (2010)	Geometric Design & Operational Factors Impacting Truck Use of Toll Roads	Surveys, design assessment of Austin, Tyler, DFW corridors	Recommended climbing lanes, short downgrades, clear signage; improved design attracts freight users & enhances safety/reliability.

Table 10. Summary of Key Government and Agency Reports (continued)

Agency / Year	Focus	Methodology / Data Sources	Key Findings & Insights
WSDOT (2011)	I-5 Express Lanes Toll Feasibility Study	Planning-level feasibility & cost–benefit analysis	Evaluated tolling scenarios for reversible lanes; documented potential revenue and diversion effects; emphasized equity and operational tradeoffs.
FDOT (2012)	I-95 Express: Lessons Learned	Post-implementation operational review	Addressed confusion in toll signage; shifted DMS messaging toward congestion info; proposed removal of toll ceiling for market-driven pricing; documented improved throughput & reliability.
USDOT / FHWA (2012)	Effective Approaches for Advancing Congestion Pricing	National synthesis of pilot and ongoing congestion pricing programs	Linked congestion pricing to economic competitiveness and freight mobility; identified modeling and communication challenges in demonstrating freight benefits.
FDOT (2014)	Express Lanes Reliability Measures	Performance monitoring and operations framework	Established 45 mph minimum operational benchmark (FHWA standard). Recommended volume-weighted travel time/speed tracking for both EL and GP lanes. Focused on reliability as primary performance measure.
USDOT (2014)	I-85 Express Lanes User Impacts Study	Two-stage panel survey (~1,600 households)	82% of EL trips were solo drivers; HOV users shifted to GP lanes, increasing occupancy there. Demonstrated redistribution of demand and behavioral adaptation under variable tolling.
MnDOT (2014)	Evaluation of the Effect of MnPASS Lane Design on Mobility and Safety	Field observations, video-based data collection, comparative analysis	Compared closed- vs. open-access HOT designs; found restricted access improves stability, while open access offers flexibility but increases lane friction near merges.
UDOT (2014)	Express Lane Utilization and Pricing Effects Study	Review of pricing, occupancy, and enforcement data	Raising tolls alone not sufficient to improve speeds; recommended increasing max tolls and raising HOV threshold to 3+ persons during peak. Highlighted elasticity of toll demand.
USDOT & FHWA (2014)	Atlanta Congestion Reduction Demonstration	Pre/post evaluation, freight surveys, transit integration	Converted 16 miles of HOV to HOT lanes with expanded park-and-ride. Freight carriers reported net benefit when time savings outweighed toll cost; improved reliability for goods delivery.

Table 10. Summary of Key Government and Agency Reports (continued)

Agency / Year	Focus	Methodology / Data Sources	Key Findings & Insights
USDOT (2015)	Evaluation of Congestion Pricing Corridors	Corridor data aggregation and emission analysis	Tolling increased corridor throughput and efficiency; observed VMT growth tied to economic recovery and decreased carpooling; overall reduced delay and improved system reliability.
UDOT (2015)	Speed–Flow Relationships and Toll Scenarios	Statistical and simulation analysis	Evaluated policy packages (education, enforcement, toll increase). EL speeds projected to increase up to 7.8 mph; effects depend on driver response and program awareness.
USDOT (2015)	Urban Partnership Agreement (UPA) National Summary	Multi-site policy evaluation (the "4Ts": Tolling, Transit, Telecommuting, Technology)	Documented increased speed reliability and person throughput across corridors. Integrated multimodal strategies enhanced accessibility and congestion management.
USDOT & Texas A&M (2016)	National evaluation of managed lane and congestion pricing programs	Policy review and program synthesis across U.S. corridors	Successful express lane programs integrate pricing with freeway management, transit, and TDM strategies. Public acceptance and equity concerns remain primary barriers to implementation.
FDOT (2017)	Tampa Bay Express (TBX) Planning-Level T&R Study	Two-phase Traffic & Revenue (T&R) analysis using Bluetooth O-D data and Surveys	Developed refined gross revenue forecasts and operational assumptions using queue accumulator tools. Demonstrated robust methodology for linking user behavior with bottleneck and queue formation analysis.
Mercator Advisors LLC & Caltrans (2017)	Express Lanes Policy Review	Legislative and policy review under P3 and concession framework	Identified public perception and policy accountability challenges. Noted lack of evaluation for freight and intermodal connectivity within existing express lane policy design.
LA Metro (2018)	Vanpool / HOV Exemption Policy	Comparative policy review of toll exemption practices	Evaluated alternative HOV exemption structures. Recommended HOV5+ toll-free eligibility.
USDOT (2018)	Express Bus Performance on Tolled Facilities	Operational and ridership data analysis	Dynamic tolling improved express bus speed and reliability. Addition of 22 new buses and 10 express routes increased corridor-level transit efficiency and multimodal performance.

Table 10. Summary of Key Government and Agency Reports (continued)

Agency / Year	Focus	Methodology / Data Sources	Key Findings & Insights
WSDOT (2019)	Express Toll Lanes: Data Analysis Report	Longitudinal operational data (speed, volume, revenue)	ETLs met all three goals: (1) user choice, (2) reliable faster travel, and (3) revenue reinvestment. Average savings of 11 minutes per trip; 23% increase in peak-period throughput.
NCHRP (2020)	Stakeholder Survey on Managed Lane Implementation	National survey of state DOTs	Revealed limited public understanding of priced managed lane goals. Identified communication and educational outreach as critical for public trust.
WSTC (2021)	Low-Income Toll Program Study	National scan and policy assessment	Found that low-income toll discounts could improve access to tolled facilities. Identified barriers such as digital access, payment systems, and enrollment complexity. Recommended integrating toll discounts with multimodal benefits.
FDOT (2022a)	Safety Effects of Managed Lane Separation Type	Crash data analysis using Safety Performance Functions (SPFs), Crash Modification Factors (CMFs), and severity distribution functions	Greater separation width between managed lanes (ML) and general-purpose lanes (GPL) improves safety. Concrete barriers reduce multi-vehicle crashes by up to 34.7% in reversible MLs. Established quantitative metrics for comparing design alternatives.
Pandey et al. (2022)	Reinforcement Learning for Dynamic Toll Optimization	Simulation-based optimization using AI (RL) and traveler equity modeling	Demonstrated that dynamic toll levels affect delay equity across user groups. Proposed value-of-time (VoT)-based discounts to mitigate delay disparities and improve fairness in toll pricing.
CDOT (2023)	High-Performance Transportation Enterprise (HPTE)	Program evaluation and performance monitoring	Highlighted institutional evolution of public–private partnerships (P3s) and revenue reinvestment practices. Emphasized balancing user reliability with financial sustainability of managed lanes.
USDOT (2023)	Overview of Highway Operations and Freight Impacts	Policy analysis and synthesis	Recognized managed lanes as integral to freight movement efficiency and general-purpose lane reliability. Highlighted freight-inclusive evaluation as a national performance priority.
FHWA (2024)	Inventory of Specialty and Managed Lane Facilities	Nationwide survey and facility database	Documented 49 operational HOT/ETL facilities with dynamic pricing across the U.S. Identified ongoing transition from HOV to HOT/ETL systems. Provided a national benchmark for lane typologies and operational practices.

2.2 Performance Metrics and Evaluation Dimensions

Evaluating the impact of EL facilities requires a multidimensional framework that captures how these facilities influence mobility, safety, reliability, and broader societal outcomes. The literature consistently demonstrates that no single metric can fully describe EL performance; rather, researchers employ multiple indicators including traffic operations, safety, travel time reliability, environmental impacts, and economic outcomes. More specifically, speed and volume metrics form the foundation for understanding operational conditions and lane interactions, while crash frequency, severity, and conflict-based measures provide insight into safety performance. Reliability indicators, such as the Buffer Index, Planning Time Index, and peak-period speed maintenance, are central to assessing the consistency of EL benefits relative to General-Purpose Lanes. Environmental evaluations increasingly rely on emissions and fuel-consumption modeling to capture sustainability implications, and economic analyses examine value of time, willingness to pay, and benefit–cost outcomes.

2.2.1 Speed and Volume

A substantial portion of empirical and statistical research has relied on speed and volume measurements to evaluate the operational impacts of ELs, HOT lanes, and other ML facilities. Early foundational work by Sullivan et al. (1997) examined the SR-91 variable-toll lanes in Southern California shortly after implementation. Using corridor-level speed and volume observations, the study noted that although most travelers were commuters, users accessed the toll lanes only occasionally, and total corridor volumes increased only marginally in the initial months. The findings highlighted how operational changes in the tolled facility affect overall traffic distribution and lane choice. Thomson et al. (2012) expanded the evaluation of managed lane traffic behavior through an extensive multi-site analysis using 15-minute aggregated speed and volume data. The study developed speed–flow curves for five different ML facility types, considering how design elements, such as separation treatments and number of lanes, affect operational performance. Of particular importance was the identification of “friction effects” whereby congestion in adjacent GP lanes can reduce managed-lane speeds, especially where passing restrictions exist. Also, design-related influences on speed and volume performance were also established in (MnDOT, 2014) assessment of HOT lanes on I-394 and I-35W. Using lane-level speed and volume data at HOT gate areas, the study demonstrated substantial speed differentials between HOT and GP lanes during peak demand, largely driven by merging and weaving at access zones. These findings highlight how ML design geometry can trigger localized shockwaves and temporary collapse of HOT lane speeds under high demand. FDOT (2014), evaluating reliability metrics for 95 Express, concluded that speed and travel time should remain the primary performance measures for ELs, recommending the use of volume-weighted travel times for both ELs and GP lanes. The report supported maintaining a reliability target of sustaining

speeds of at least 45 mph for 90% of peak travel, a standard directly linked to throughput preservation and congestion prevention.

Avelar et al. (2016) provided a detailed statistical investigation of ML–GP interactions using 30-second speed and volume data from two buffer-separated ML sites in Houston, one with pylons and one without. Through Gaussian mixed-effects modeling, the study confirmed that ML speeds increase with GP lane speeds and decrease with GP density. Importantly, pylons reduced the influence of GP lane turbulence on ML speeds, demonstrating how physical separation mitigates frictional impacts. Complementing these findings, (Sajjadi & Kondyli, 2017) analyzed one-lane and two-lane HOT segments in South Florida using both macroscopic capacity analysis and VISSIM microsimulation. The research quantified differences in speed-flow relationships across segment types: the one-lane HOT segment experienced a 7.6% drop in capacity after breakdown, while the two-lane segment maintained stable post-breakdown flow. These results emphasize how HOT lane width and separation affect achievable speeds and resiliency during high-volume conditions. However, at the corridor level, WSDOT (2019) long-term evaluation of I-405 Express Toll Lanes incorporated six-month speed and volume reporting to assess performance against statutory requirements. Although not all segments met the threshold of maintaining ≥45 mph for 90% of peak periods, many sections did, and overall ETL operations improved person throughput and maintained higher peak speeds relative to GP lanes.

Additional insights linking speed/volume dynamics to safety outcomes were provided by Fu et al. (2023), who developed hierarchical safety performance functions for reversible and HOV corridors using detector-based speed and volume data. While focused on crash prediction, the study found that larger volume and speed differentials between special-use lanes and GP lanes correlated with higher crash frequencies, underscoring the operational importance of maintaining balanced lane speeds. More recently, Biswas et al. (2024) evaluated six ML facilities across the United States using nine performance measures, including speed, volume, and travel time reliability, to compare the effectiveness of variable versus dynamic tolling. Although both strategies successfully maintained traffic flow on managed lanes, dynamic pricing showed a slight advantage on most speed and reliability metrics. Crucially, the study confirmed that both pricing mechanisms can sustain desirable ML operating speeds while managing volume efficiently. Table 11 summarizes the speed and volume evaluation studies.

Table 11. Speed & Volume Evaluation Studies

Author (Year)	Study Title	Methodology / Evaluation Metrics	Key Findings
Sullivan et al. (1997)	Impacts of SR-91 Variable-Toll Lanes	Corridor speed & volume monitoring; traveler behavior analysis	Toll lane use was occasional; peak-period volumes increased modestly; managed lanes altered lane-choice behavior without major volume shifts.
Thomson et al. (2012)	Traffic Flow Behavior of Managed Lane Facilities	15-min speed & volume data; speed–flow curve development	Identified friction effects from GP lanes; developed speed-flow curves for 5 ML configurations; passing restrictions & separation type significantly affect performance.
MnDOT (2014)	Effect of HOT Lane Design on Mobility & Safety	Lane-level speed/volume data at gates; video-based weaving analysis	HOT lane gates create speed differentials; high-demand weaving zones trigger shockwaves and localized HOT speed drops.
FDOT (2014)	Express Lanes Reliability Measures	Travel-time, speed, and volume-weighted reliability metrics	Recommends 45 mph reliability threshold (90% of peak travel); speed/volume metrics provide most stable indicator of EL performance.
Avelar et al. (2016)	Influence of GP Lanes on ML Performance	30-sec speed/volume data; Gaussian mixed-effects modeling	ML speeds rise with GP speeds; pylons reduce friction effects; GP congestion has measurable spillover impact on ML operations.
Sajjadi & Kondyli (2017)	HOT Lane Operational Analysis	Macroscopic capacity analysis; VISSIM	One-lane HOT with pylons had capacity drop after breakdown; two-lane HOT more stable; speed-flow relationships highly design-dependent.
WSDOT (2019)	I-405 Express Toll Lanes: 45-Month Analysis	speed/volume performance	ETLs improved peak-period speeds; many segments met ≥45 mph 90% reliability; increased total corridor throughput.
Fu et al. (2023)	Volume & Speed Effects on Safety in Managed Lanes	MVDS speed/volume	Large speed/volume differentials between ML & GP lanes associated with higher crash frequencies; operational imbalance creates safety risks.
Biswas et al. (2024)	ML Performance Under Dynamic vs. Variable Pricing	Evaluation using 9 performance metrics (speed, volume, TTR, etc.)	dynamic pricing slightly outperforms variable pricing on speed & reliability; MLs consistently operate above GP speeds.

2.2.2 Safety

Safety performance has been a central focus of empirical research evaluating the impacts of ELs, HOT lanes, and ML configurations nationwide. A consistent finding across studies is that the introduction or conversion of managed lanes does not degrade overall freeway safety, and in many cases yields measurable reductions in crash frequency or severity.

One of the earliest and most influential studies, Abuzwidah et al. (2014) conducted a rigorous before–after safety evaluation using both cross-sectional methods and a multivariate Empirical Bayes framework. The study, which analyzed the conversion of traditional main-line toll plazas to hybrid main-line toll plaza systems, demonstrated that the proposed method provided the most

reliable crash modification factors and showed an overall reduction in crashes following the conversion. Further insight into operational design and safety interactions was provided by the Minnesota Department of Transportation (MnDOT, 2014), which examined differences between closed-access (I-394) and open-access (I-35W) MnPASS HOT lanes. Through detailed video-based traffic observation, MnDOT found that closed-access designs improved lane discipline and reduced turbulence, while open-access configurations. though more flexible, introduced localized friction at merge areas. These findings underscore the role of access management in mitigating safety risks at EL entry/exit points. Building on this direction, using advanced machine-learning methods, Kitali et al. (2021) evaluated injury severity outcomes across four California Express Lane facilities. Their Support Vector Machine model, optimized using a Firefly Algorithm, identified concrete barriers, high AADT, mountainous terrain, adverse weather, nighttime conditions, and weekend periods as key factors increasing crash severity. Wider shoulder widths were associated with reduced injury likelihood. This work highlighted the importance of geometric design and roadway context in managing Express Lane safety performance.

At a methodological level, Yuan et al. (2021) demonstrated the feasibility of developing Safety Performance Functions (SPFs) at multiple spatial aggregation levels using microscopic detector data across California, Florida, and Virginia. Their results showed that HOV and HOT lanes exhibited lower crash frequencies under various operating conditions, suggesting that managed-lane separation and controlled access strategies can enhance safety outcomes when properly designed. A more comprehensive evaluation specific to Florida was conducted in FDOT (2022a), which analyzed 95 Express and 595 Express alongside comparable managed lanes in Texas and Georgia. The study developed SPFs, Crash Modification Factors (CMFs), and severity distribution functions, distinguishing between non-reversible and reversible facilities and between separation types (pylons vs. concrete barriers). Findings indicated that, for non-reversible facilities, both fatal/injury and property-damage-only crashes decreased as separation width increased, while multi-vehicle crashes increased modestly with each additional managed lane. For reversible facilities, increases in separation width with concrete barriers significantly reduced multi-vehicle crash frequencies. This work provided one of the strongest empirical foundations for data-driven lane separation and geometric design policies. Building on these themes, Rim et al. (2023) developed Poisson–Lognormal SPFs for weaving segments across Florida, Kansas, and Michigan. Their findings highlighted that weaving conflicts and traffic interactions, not geometry alone, are primary contributors to crash risk in segments where ELs interface with GPLs. This reinforces the view that access-point design and traffic composition are critical determinants of managed-lane safety.

A more recent Florida-focused analysis by Abuzwidah & Abdel-Aty (2024) used 55 miles of Express Lane corridors, including I-95, applying before–after models and cross-sectional techniques. The study found that EL facilities consistently exhibited CMFs below, indicating improved safety, while GP lanes displayed slight increases in crash frequency, suggesting a redistribution effect rather than a net increase in system-wide crashes. Finally, Faden et al. (2025)

advanced safety modeling by incorporating microscopic detector data and using a Poisson Lognormal Lindley framework with a copula-based dependency model to examine safety interactions between Express Lanes and adjacent GP lanes on the I-4 Ultimate corridor. The study showed that lane occupancy in the rightmost GP lane significantly influences EL crash likelihood, especially near merge segments, emphasizing that Express Lane safety is tightly coupled with GPL operational conditions. Table 12 summarizes the safety-oriented evaluation studies.

Table 12. Safety Oriented Evaluation Studies

Author (Year)	Study Title	Methodology / Evaluation Metric	Key Findings
Abuzwidah et al. (2014)	Safety Evaluation of Hybrid Main-Line Toll Plazas	Before–After analysis, Multivariate Empirical Bayes; crash frequency & CMFs	HMTP conversion reduced crashes; supported later findings that EL/HOT conversions do not compromise safety.
MnDOT (2014)	Evaluation of MnPASS Lane Design on Mobility and Safety	Video-based traffic observation; speed–flow & turbulence analysis	Closed-access HOT lanes improved lane discipline and reduced turbulence; open-access designs created friction at merge areas.
Kitali et al. (2021)	Injury Severity Analysis for Express Lane Crashes	Support Vector Machine (SVM) severity modeling	Crash severity increases with concrete barriers, high AADT, mountainous terrain, adverse conditions; wider shoulders reduce severity.
Yuan et al. (2021)	Developing Safety Performance Functions for Managed Freeways	SPFs using microscopic detector data (negative binomial models)	HOV/HOT lanes showed lower crash frequencies across multiple aggregation levels; supports safety benefits of managed lanes.
FDOT (2022a)	Safety Performance of Managed Lane Separation Types	SPFs, CMFs, severity distribution functions; stratified by severity/collision type; comparison across FL, TX, GA	Wider separation with pylons reduces FI/PDO crashes in non-reversible lanes; barriers reduce MV crashes in reversible lanes. Additional MLs slightly increase MV crash risk.
Rim et al. (2023)	Safety Performance Functions for Freeway Weaving Segments	Poisson–Lognormal SPFs; AIC-driven variable selection	Traffic interactions (weaving flows) are primary crash contributors, not geometry alone; important for EL access design.
Abuzwidah & Abdel-Aty (2024)	Crash Performance of Express Lanes and General Purpose Lanes	Cross-sectional + Before–After EB; lane-level crash frequency	ELs show CMFs < 1 (improved safety); slight crash increases in GPLs indicate redistribution, not system-wide increase.
Yang et al. (2024)	Predicting Crashes on I-4 Express Managed Lanes	CNN + LSTM prediction models; lane-level MVDS data	ADL models effectively estimate crash likelihood despite low crash counts; merge areas show elevated crash risk.
Faden et al. (2025)	Short-Term Safety Analysis of I-4 Ultimate Express Lanes	Poisson Lognormal Lindley model; copula dependency analysis; microscopic detector data	Rightmost GP lane occupancy strongly influences EL crashes; merge segments show highest risk; significant EL–GPL safety interdependencies.

2.2.3 Travel Time Reliability

Travel time reliability has emerged as one of the most widely adopted performance measures for evaluating the operational effectiveness of ELs and their influence on adjacent GP lanes. Early guidance on this topic is provided by the FDOT (2014), which remains the foundational Florida

document codifying reliability as a central operational objective. FDOT formally recommends the use of volume-weighted travel times for both ELs and GP lanes and establishes the performance standard of maintaining travel speeds of at least 45 mph for 90% of peak-period operations. This standard, mirroring FHWA's national requirements, anchors travel time reliability as the core benchmark against which EL effectiveness is evaluated. Building on statewide guidance, several empirical studies have quantified real-world reliability improvements on managed lane facilities. Cheng et al. (2014) examined a 7-mile segment of the southbound I-95 Express in Miami using a VISSIM-integrated toll optimization model that incorporated travel time reliability, trip purpose, and user income. Their modified dynamic tolling algorithm generated more stable toll adjustments, higher overall revenue, and, critically, more frequent maintenance of speeds exceeding 45 mph relative to the corridor's existing strategy. This demonstrated that integrating reliability into toll-setting frameworks can yield more consistent operating conditions while enhancing financial performance.

Beyond these evaluations, machine-learning-enabled and control-theoretic studies have further expanded reliability-focused methodologies. Zhang et al. (2019) developed an improved random forest lane-choice prediction algorithm using 5-minute interval data from I-405 in Washington. The resulting dynamic pricing strategy significantly reduced total delay and improved travel time reliability, achieving accuracy levels substantially higher than competing models. Jin et al. (2020) formalized reliability within a theoretical HOT lane control framework, identifying two core operational objectives: (i) maintaining HOT lane free-flow to guarantee reliable travel times and (ii) maximizing throughput to minimize total system delay. By applying integral-controller-based feedback mechanisms across alternative lane-choice models, the study demonstrated that dynamic tolls can be tuned to maintain stable and predictable travel times even under uncertainty in user behavior. Corridor-specific empirical research has reinforced these insights. Kadeha et al. (2020) evaluated reliability on the I-95 Express Lanes using the Buffer Index (BI) derived from RITIS data. Express Lanes exhibited consistently lower BI values compared with GP lanes, confirming superior reliability. Moreover, GP lane reliability improved measurably when ELs were operational, suggesting corridor-wide stabilization benefits. More recent work has integrated equity considerations into reliability assessments. Pandey et al. (2022) along with NCDOT formulated a reinforcement-learning-based dynamic pricing model that evaluated delay distributions across different traveler groups, rather than relying on a single index such as BI or PTI. Advancing toward predictive and personalized control strategies, Xie et al. (2024) introduced a real-time tolling system that integrates dynamic traffic assignment (DTA), short-term traffic prediction, and multi-objective system optimization. Closed-loop simulations based on real operational data showed that the predictive tolling system outperformed reactive policies by achieving higher revenues, improved lane utilization balance, reduced corridor congestion, and enhanced travel time reliability. Importantly, the framework provides tunable policy parameters allowing operators to prioritize reliability, revenue, equity, or congestion mitigation according to corridor goals. Table 13 summarizes the travel time reliability-oriented evaluation studies.

Table 13. Travel Time Reliability Oriented Evaluation Studies

Author (Year)	Study Title	Methodology / Reliability Metric	Key Findings
FDOT (2014)	*Express Lanes Reliability Measures*	Operational monitoring; volume-weighted travel time; ≥45 mph for ≥90% of peak hours	Establishes Florida's formal reliability standard; identifies travel time and speed as primary EL performance metrics
Cheng et al. (2014)	*Modified Dynamic Tolling for I-95 Express*	VISSIM microsimulation; reliability measured via speed maintenance >45 mph; toll stability	Modified pricing algorithm maintained higher % of speeds above 45 mph, produced steadier tolls, and increased revenue versus existing strategy.
Zhang et al. (2019)	*Dynamic Pricing Using ML for Managed Lanes*	5-min historical traffic & toll data; Random Forest (RF) prediction; reliability via delay reduction	Improved RF model achieved 88.7% accuracy; dynamic pricing significantly reduced total delay and improved reliability vs. baseline tolling.
Jin et al. (2020)	*Dynamic HOT Lane Pricing with Free-Flow Target*	Point-queue model; lane choice modeling; reliability via maintaining HOT free-flow	Demonstrates strong linear correlation between dynamic tolls and excess GP queueing; feedback controller maintained reliable HOT free-flow travel conditions.
Kadeha et al. (2020)	*Travel Time Reliability Analysis for I-95 Express*	RITIS detector data; Buffer Index (BI); Welch's t-test	ELs showed consistently lower (better) BI values than GP lanes; GP lanes also showed improved BI when ELs were open → corridor-wide reliability benefits.
Pandey et al. (2022)	*Reinforcement Learning for Equitable Dynamic Tolling*	RL-based optimization; reliability measured via delay distributions across traveler classes	Demonstrates how dynamic toll discounts tied to value of time reduce reliability inequities; methodology applicable to freight/passenger comparison.
Xie et al. (2024)	*Personalized Predictive Tolling for Managed Lanes*	Real-time traffic prediction + DTA; multi-objective reliability optimization	Predictive tolling increased travel-time reliability, reduced congestion, improved ML/GP utilization balance

2.2.4 Emissions

A growing body of empirical and simulation-based research has examined how ELs and other ML strategies influence corridor-level emissions, vehicle activity patterns, and broader environmental outcomes. Much of this literature emphasizes that operational improvements, such as higher and more reliable speeds, can have mixed effects on emissions depending on traffic flow conditions, vehicle technology, and the spatial distribution of demand.

At the national level, the U.S. Department of Transportation's multi-site evaluation of congestion-pricing deployments under the Urban Partnership Agreement (UPA) and Congestion Reduction Demonstration (CRD) programs provided an early foundation for understanding environmental outcomes (USDOT, 2015). Across six metropolitan areas, including Miami, Los Angeles, and Seattle, tolling generally improved travel-time reliability and person-throughput; however, some corridors exhibited increases in total emissions due to region-wide growth in vehicle miles traveled (VMT). This finding highlighted the difficulty of attributing emissions changes solely to pricing interventions when regional travel patterns are simultaneously evolving.

A major methodological advancement came from X. Xu et al. (2016), who developed an automated coupling between VISSIM microsimulation and the U.S. EPA's MOVES emissions model using the MOVES-Matrix framework. By pre-computing hundreds of millions of MOVES runs across vehicle, fuel, environmental, and operating regimes, the MOVES-Matrix allowed emissions to be estimated directly from VISSIM-generated speed–acceleration trajectories. Sensitivity analyses revealed that several internal VISSIM parameters, including car-following aggressiveness and lane-changing behaviors, substantially influence emissions outcomes at both link and corridor scales. The study demonstrated that microsimulation-based emissions evaluation is powerful but must be treated carefully to avoid erroneous conclusions. At broader spatial scales, Javid et al. (2017) conducted a nationwide regression analysis relating HOV lane mileage and socioeconomic variables to carpooling behavior across all 50 U.S. states. Their findings indicated that greater HOV lane availability and higher gasoline prices correlate with increased carpooling propensity, implying reductions in CO_2 and criteria pollutant emissions. While not focused specifically on Express Lanes, this work offers an important macro-level benchmark by linking managed lane supply to regional environmental performance.

Several project-level before–after studies provide more direct evidence regarding emissions impacts of lane conversion. Y. (Ann) Xu et al. (2017) evaluated the conversion of Atlanta's I-85 HOV corridor to HOT lanes using detailed vehicle activity data collected by Georgia DOT. When assessed with the MOVES model while holding the analysis year constant to control for fleet turnover, the authors found that peak-hour mass emissions for several pollutants increased by up to 17 percent, even as CO_2 remained relatively stable. This result underscores the importance of isolating operational changes from broader technological trends, and cautions against assuming that managed lane conversions inherently reduce emissions. Complementary evidence from Du et al. (2021) illustrates the nuanced relationship between microscale driving behavior and macroscale emissions outcomes. In a Houston corridor featuring managed lanes, the authors used second-by-second trajectory data and ANOVA tests to compare driving patterns between EL and GP lanes. Managed-lane users exhibited smoother profiles, higher average speeds and fewer hard accelerations, which increased per-vehicle emission rates expressed in grams per hour. However, because overall traffic volumes in managed lanes were lower and congestion was reduced, total corridor-level emissions (NO_x and hydrocarbons) were substantially lower, between 32% and 43% of those observed on GP lanes. Importantly, the study noted that Houston's air-shed is hydrocarbon-limited, meaning that even moderate reductions in HC emissions can yield meaningful improvements in local ozone formation potential.

More recent work by Yang et al. (2025) extends emissions evaluation into the policy domain by examining how toll discounts influence carbon emissions in freight-intensive corridors. Using the COPERT emissions model and trip-level data, the study found that toll discounts can increase highway utilization among freight carriers, which, counterintuitively, reduced system-wide CO_2 emissions by shifting freight activity away from slower, more congested routes. On average, each kilometer of incentivized highway travel generated a net reduction of roughly 52 g of CO_2 per day.

However, the study warned that improperly calibrated toll reductions could induce additional passenger travel, partially offsetting freight-related benefits. Table 14 summarizes the environmentally oriented evaluation studies.

Table 14. Environmentally Oriented Evaluation Studies

Author (Year)	Study Title	Methodology / Evaluation Metric	Key Environmental / Economic Findings
USDOT (2015)	Urban Partnership Agreement & CRD Program Evaluation	Multi-site empirical evaluation; person-throughput, emissions, VMT, travel-time reliability	Tolling improved reliability; some corridors showed higher total emissions due to increased VMT despite operational gains.
Xu et al. (2016)	Integrating VISSIM with MOVES via MOVES-Matrix for Emissions Analysis	Microsimulation + MOVES-Matrix (hundreds of millions of emission-rate lookup runs)	Demonstrated that VISSIM parameters significantly affect emission outcomes; introduced a robust framework for link/corridor emission estimation.
Javid et al. (2017)	Nationwide Environmental Effects of HOV Lane Expansion	Regression analysis of HOV lane-kilometers, gas prices, and carpooling rates across 50 U.S. states	Greater HOV lane availability increases carpooling; inferred reductions in CO_2 and criteria pollutants at the state level.
Xu et al. (2017)	I-85 HOT Conversion Environmental Analysis (Atlanta)	Before–after MOVES-based emissions analysis using vehicle activity data	When controlling for fleet turnover, peak-hour pollutant mass emissions increased up to 17%; CO_2 stable;
Du et al. (2021)	Emissions Comparison Between Managed Lanes and GP Lanes (Houston)	Second-by-second driving data, ANOVA; activity-based emissions estimation	ML users had smoother driving but higher per-vehicle emissions (g/h); total corridor-level NOx/HC emissions were 32–43% lower due to reduced congestion.
Yang et al. (2025)	Toll Discount Impacts on Carbon Emissions Using COPERT	Econometric analysis + COPERT model for trip-level CO_2 estimation	Toll discounts reduce overall system-wide emissions by shifting freight to higher-speed facilities; average savings ~52 g CO_2 per km/day; warns of induced passenger demand.

2.2.5 Economic Metrics

From an economic standpoint, a substantial body of research has assessed how travelers value EL services, how tolling influences willingness to pay, and how corridor performance translates into broader societal benefits. Devarasetty et al. (2012) provided one of the earliest rigorous econometric examinations by conducting a stated-preference survey of travelers on Houston's Katy Freeway. By comparing Bayesian D_β-efficient, random-level, and adaptive-random experimental designs, the authors estimated mixed logit models of the value of travel time savings (VTTS) and found large discrepancies across survey designs. Complementing user-based valuation studies, the national evaluation of the Atlanta Congestion Reduction Demonstration (USDOT, 2014) incorporated environmental, goods-movement, and business-impact components that indirectly reflect economic performance. The analysis found generally positive environmental outcomes and modest fuel consumption reductions attributable to smoother EL operations. For freight, small commercial vehicles that were eligible for Express Lanes experienced travel-time improvements, although operators offered mixed assessments regarding net business benefits.

Small businesses located along the corridor expressed concern that congestion in general-purpose (GP) lanes had not improved sufficiently following the EL conversion, highlighting that economic perceptions can diverge from operational metrics.

At a broader scale, Casady et al. (2020) conducted a simplified social benefit–cost analysis (BCA) across seven mature U.S. managed-lane projects. Their results showed that project benefit–cost ratios were highly sensitive to VTTS assumptions. In particular, typical VTTS values used in planning models tended to undervalue the premium associated with reliable, uncongested travel provided by Express Lanes. This finding suggests that conventional BCAs may systematically underestimate the true economic value of travel-time reliability improvements, an issue especially relevant in freight-dense corridors. Also, considering social-oriented economic evaluations, the NCDOT alongside Pandey et al. (2022) applied reinforcement-learning–based toll optimization to examine how dynamic tolls affect travelers with different income levels and values of time (VOT). The study demonstrated that VOT-proportional toll discounts can reduce delay inequities across user groups while still maintaining strong operational performance. Most recently, Lin et al. (2024) combined revealed-preference transponder data with probe-based travel-time measurements to estimate willingness to pay for Express Lane use in Virginia before and after the COVID-19 pandemic. The study found that longer EL segments tended to generate higher willingness to pay, while peak-period valuations dropped in the post-pandemic period due to growth in telecommuting and flexible work schedules. These findings highlight how behavioral and structural changes in travel demand can materially alter the economic performance of managed-lane facilities. Table 15 summarizes the economically oriented evaluation studies.

Table 15. Economically Oriented Evaluation Studies

Author (Year)	Study Title	Methodology / Evaluation Metric	Key Economic Findings
Devarasetty et al. (2012)	*Value of Travel Time Savings on Houston's Katy Freeway Managed Lanes*	Stated-preference survey (Bayesian D_β-efficient, random-level, adaptive-random designs);	VTTS estimates vary drastically by survey design; Shows economic valuations of ELs highly sensitive to methodology.
USDOT & FHWA (2014)	*Atlanta Congestion Reduction Demonstration—National Evaluation*	Environmental, goods-movement, and business-impact analyses; qualitative economic assessment	ELs improved travel times for small commercial vehicles; mixed business perceptions; environmental improvements noted.
Casady et al. (2020)	*Benefit–Cost Assessment of Managed Lane Projects*	Simplified BCA applied to seven U.S. ML corridors; sensitivity to VTTS	Traditional VTTS values underestimate worth of reliable EL travel. ELs deliver larger economic benefits than typically captured in BCAs.

Table 15. Economically Oriented Evaluation Studies (continued)

Author (Year)	Study Title	Methodology / Evaluation Metric	Key Economic Findings
Pandey et al. (2022)	*Equity Impacts of Dynamic Tolling—RL-Based Optimization*	Reinforcement-learning toll optimization; income- and VOT-stratified delay analysis	VOT-proportional discounts reduce delay inequities; toll levels strongly influence distributional economic outcomes across user groups.
Lin et al. (2024)	*Revealed Preference Valuation of Express Lane Travel Before and After COVID-19*	Toll transponder data + probe-based travel times; econometric estimation of willingness to pay (WTP)	Longer ELs produce higher WTP; post-pandemic WTP declines during peaks due to telecommuting flexibility; economic valuation depends on corridor length & congestion intensity.

2.3 Document Types

Following the detailed review of methodological approaches and evaluation metrics, it is important to emphasize that peer-reviewed academic studies and government agency reports differ substantially in their purpose, analytical rigor, and treatment of EL impacts.

In general, peer-reviewed journal papers focus on methodological innovation, often proposing new models, optimization frameworks, or simulation techniques, while using existing managed lane facilities primarily as case studies to demonstrate methodological performance. Conversely, government reports produced by federal and state DOTs are not designed to introduce novel methods. Instead, they focus on evaluating the real-world performance of the specific facility of interest, relying on operational monitoring, policy evaluation, and data-driven performance reporting that directly supports agency decision-making.

To clearly articulate these distinctions, the comparison in this review is organized around two methodological categories:

i. simulation and modeling approaches, and
ii. statistical and empirical analyses.

Results shown in Figure 2 indicate that peer-reviewed research is far more methodologically diverse. While both clusters. simulation/modeling and statistical/empirical analyses, appear in roughly comparable proportions in the academic literature, the underlying complexity and novelty of methods used in journal studies is substantially greater than in agency reports. In contrast, as shown in Figure 3, government reports overwhelmingly rely on empirical monitoring rather than simulation or modeling to evaluate EL performance. Across all documents examined, only one government report, the USDOT–NCDOT alongside Pandey et al. (2022) study, implemented a genuine mathematical modeling framework, applying a reinforcement-learning-based dynamic pricing model to evaluate delay distribution across user groups. This stands out as the sole example of advanced optimization being natively developed within an agency report.

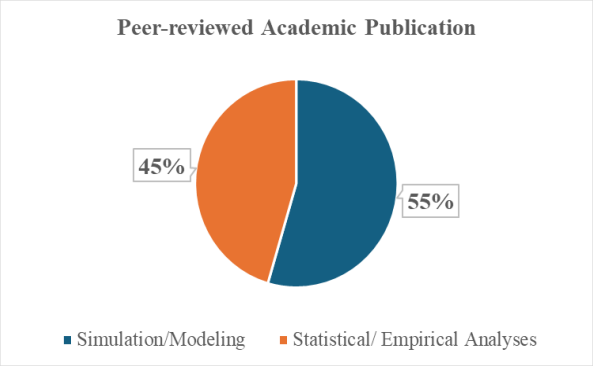


Figure 2. Distribution of Methodological Approaches in Peer-Reviewed Academic Publications

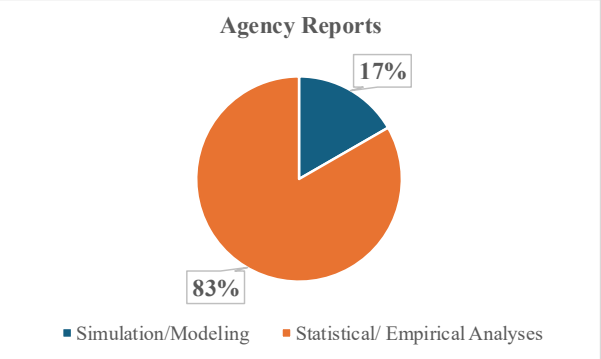


Figure 3. Distribution of Methodological Approaches in Agency Reports

With respect to evaluation metrics, the differences are equally pronounced. This review focuses on five major performance dimensions commonly evaluated in both academic and agency contexts:

- speed and volume
- travel time reliability
- safety
- environmental
- economic

As illustrated in Figure 4, peer-reviewed publications show a strong emphasis on safety, particularly through advanced statistical modeling, machine learning, and before–after frameworks. Speed and volume constitute the second largest category, reflecting foundational empirical studies often conducted during the early phases of managed lane deployment. Travel time reliability occupies a smaller share of academic focus compared with safety and operations, though still more frequently than environmental or economic analyses, which remain relatively rare. On the other hand, results presented in Figure 5 show that among government reports, the most prominent areas of evaluation are economic considerations and speed/volume metrics, reflecting the operational monitoring priorities of DOTs. Safety and reliability also appear consistently, but environmental assessment receives the least attention in agency documents, at least within the set reviewed for this project.

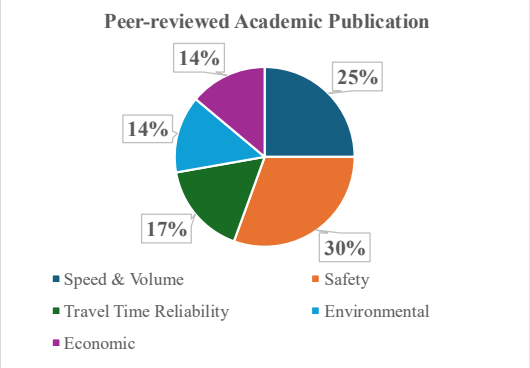


Figure 4. Distribution of Evaluation Metrics in Peer-Reviewed Academic Publications

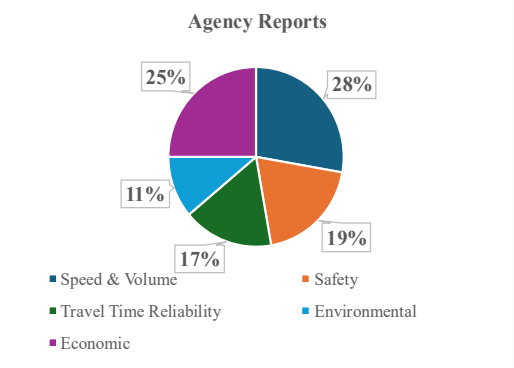


Figure 5. Distribution of Evaluation Metrics in Agency Reports

3 State of the Practice Assessment

The purpose of this section is to review and synthesize peer agency practices, institutional procedures, and operational approaches used across the United States to evaluate the impacts of managed and tolled lane facilities on freight mobility. Subtask 1.2 focuses not on academic research methods, but rather on how state DOTs, MPOs, and toll authorities actually assess Express Lane impacts in real-world planning, operations, and policy contexts.

A key challenge encountered during this review is the limited availability of government or agency reports that explicitly evaluate freight-specific outcomes resulting from EL implementation. As demonstrated in the previous section, only a small number of DOT reports, most prominently from TxDOT, directly examine commercial vehicle behavior, trucking industry responses, or freight-related performance metrics. Most statewide and federal EL evaluations primarily emphasize general mobility, reliability, safety, or revenue outcomes, with freight impacts mentioned only indirectly or not at all.

Given this scarcity, and recognizing that Express Lanes operate within the broader family of Managed Lanes, this assessment necessarily broadens its scope to include state-of-the-practice findings from HOV, HOT, and other managed lane programs. These facilities share common design characteristics, operational strategies, pricing mechanisms, and data requirements. More importantly, they employ comparable evaluation methodologies, such as speed and volume monitoring, reliability measurement, safety analysis, and structured stakeholder engagement, that are directly transferable to assessing Express Lane impacts on freight mobility. Also, in order to further underscore the limited availability of freight-focused evaluations, this assessment also incorporates the very small number of peer-reviewed journal studies that explicitly examine the effects of Express Lane implementation on freight operations. Including these academic sources helps fill critical gaps in agency reporting and provides additional context for understanding how freight movement is influenced by managed lane strategies.

3.1 Overview of Peer Agency Practices

A substantial set of government and agency reports have evaluated how tolling, managed lanes, and express lanes influence freight movement, trucking operations, and broader economic performance. These studies complement academic work by providing real-world operational insights, empirical data, and practitioner-oriented recommendations that are directly relevant to evaluating the freight implications of ELs across the nation.

One of the earliest freight-focused assessments was conducted by the Texas Department of Transportation (TxDOT, 2010), which surveyed trucking companies across commodity sectors, trip types, and operating characteristics. The study sought to quantify how different segments of the trucking industry respond to traditional toll roads, variably priced facilities, mixed-flow express lanes, and truck-only toll lanes. Results indicated that congestion is perceived as a major operational barrier, with more than 30% of carriers reporting strict delivery windows of one to two hours. Time sensitivity was statistically linked to willingness to use tolled or priced facilities. Carriers already using toll roads held markedly more favorable perceptions of tolling, a relationship confirmed through chi-square analysis. These findings highlight the importance of reliability for freight, and indicate that tolled or express facilities may be particularly valuable for time-sensitive segments of the trucking industry. In addition, a companion TxDOT guide (TxDOT & FHWA, 2010) expanded the analysis by evaluating how roadway geometry, signage, operations, and ramp design influence truck use of tolled and managed corridors. Using field observations and industry feedback, the guide identified several key design elements, such as horizontal/vertical alignment, climbing lanes, access/egress geometry, signing, ITS, and pavement markings, that can materially affect freight adoption of managed lanes. The report produced a series of design and operational recommendations, such as avoiding long downgrades, optimizing ramp curvature for heavy vehicles, and installing active curve-warning systems. These recommendations demonstrate how design and infrastructure characteristics directly influence freight willingness to use EL/HOT corridors.

At the national level, the U.S. Department of Transportation's congestion-pricing guidance (USDOT, 2012) emphasized that freight-intensive industries are particularly sensitive to congestion and unreliability, which can degrade economic competitiveness. The report also noted limitations of regional travel-demand models in capturing freight responses to pricing (e.g., inability to model time-sensitive cargo, limited representation of truck value of time). Many regions, including freight hubs such as Chicago, revealed that their models underestimated potential freight benefits of congestion-pricing strategies, underscoring the need for better freight-specific modeling inputs when evaluating EL operations. Also, the national evaluation of the Atlanta Congestion Reduction Demonstration (USDOT, 2014) offers a robust example of how managed lanes influence freight corridors in practice. In converting I-85 from HOV to HOT, the evaluation included analyses of goods movement and business impacts. Small commercial vehicles experienced improved travel times when using the Express Lanes, whereas operators traveling in the general-purpose lanes reported slower speeds. Commercial carriers held mixed

views regarding the net benefit to their operations, while small business owners expressed skepticism about congestion improvements. This study demonstrates the heterogeneous freight response to lane conversions and provides a useful template for how freight operators can be integrated into EL evaluation frameworks. The Urban Partnership Agreement (UPA) national evaluation (USDOT, 2015) offered further freight-relevant findings across Miami, Atlanta, Los Angeles, Minneapolis, San Francisco, and Seattle. Monetized benefits included savings in auto, truck, and transit travel time, reduced emissions, lower fuel consumption, and, where available, vehicle operating cost reductions. The inclusion of truck travel-time benefits in the economic analysis provides a strong national precedent for quantifying freight outcomes of express-lane deployments. More recent assessments continue to highlight implementation challenges and freight-relevant considerations. NCHRP (2020) surveyed DOTs and MPOs nationwide, identifying goals, performance measures, and communication barriers related to priced managed lanes. The report found that confusion or misunderstanding among stakeholders, including freight operators, often complicates messaging around managed-lane purpose and benefits. This insight is crucial for framing freight outreach strategies. Finally, WSDOT's low-income toll program study (Washington State Transportation Commission, 2021) briefly referenced the SR-167 master plan, which identifies the corridor as both a major commuter and freight route. Although the study focused primarily on toll equity programs, its recognition of freight as a core corridor function reinforces the broader principle that express-lane policies must account for freight access, reliability, and economic implications.

Florida-focused documents from this period, although centered on high-priority freight corridors such as I-95 and its associated Express Lane facilities, do not directly evaluate the importance of these facilities for freight mobility. FDOT's 2012 *95 Express Lessons Learned* report, for example, examined tolling strategy, traveler information, and performance monitoring practices along one of the state's most freight-relevant corridors. While freight was not a primary focus, the report demonstrated FDOT's approach to monitoring speeds, volumes, and travel-time reliability on a corridor that carries substantial truck traffic serving PortMiami and Port Everglades. Similarly, FDOT's 2014 assessment provided a deeper evaluation of travel-time and speed data sources, including those applicable to truck monitoring. The report emphasized I-95's multimodal importance, serving passenger vehicles, transit services, and freight flows, and highlighted severe peak-period congestion where travel times often doubled relative to free-flow conditions. However, despite acknowledging the corridor's freight significance in introductory sections, the analysis did not explicitly link Express Lane performance findings to freight operations.

Thus, a clear gap emerges when examining existing government reports studies evaluating the impacts of Express Lanes and/or other Managed Lanes facilities on freight mobility, as freight considerations are rarely analyzed in depth. With the exception of a handful of Texas-based studies from 2010 that directly surveyed trucking industry behavior, most government evaluations only mention freight indirectly, typically in the context of corridor importance, reliability improvements, or general accessibility, but do not explicitly assess freight operations, freight

performance metrics, or commercial vehicle outcomes. This lack of freight-focused analysis is striking given the critical role heavy-duty vehicles play in congestion, safety, emissions, and economic performance along major expressway corridors.

3.2 Overview of Peer Reviewed Academic Publications

The same pattern is seen in the academic literature. Across hundreds of Express Lane, HOV/HOT lane, and managed lane studies published over the last two decades, our research team managed to identify only two peer-reviewed journal papers that directly examine freight behavior or freight-related outcomes. These studies underscore both the scarcity of freight-centered research and the importance of addressing this gap.

More specifically, Y. (Ann) Xu et al. (2017) provide one of the few detailed analyses of freight vehicle behavior in the context of a managed lane conversion. Evaluating the HOV-to-HOT conversion on I-85 in Atlanta using MOVES emissions modeling and before–after vehicle activity data, the authors documented substantial shifts in vehicle class distributions. After conversion, passenger car usage increased significantly on the HOT lane, while both light-duty and heavy-duty trucks decreased, suggesting that commercial vehicles were less inclined, or less permitted, to use the priced lane. In contrast, the share of light- and heavy-duty trucks increased on the general-purpose lanes, with total corridor heavy-truck share rising from 5.6% to 5.8%. These findings imply potential freight displacement effects, increased truck exposure to congestion, and altered emissions outcomes, yet such effects are seldom explored in government evaluations.

More recently, Yang et al. (2025) similarly highlights meaningful freight-specific responses to tolling and pricing. Using large-scale ETC data, the study distinguishes passenger and freight traffic compositions, observing that Type 5 heavy-duty trucks (five-axle units) account for over 64% of freight vehicle activity, and Type 1 light-duty trucks for another 25%. Importantly, heavy-duty trucks exhibit a clear emissions-speed relationship, with CO_2 emissions stabilizing above 50 mph. The study finds that toll discount policies generate immediate behavioral responses from freight carriers (in contrast to delayed responses among passenger vehicles) and that shifting freight from slower surface streets to high-speed highways produces a net system-wide reduction of 52 g CO_2 per kilometer per day, despite localized increases in highway emissions. Taken together, these results highlight the unique behavioral and operational characteristics of freight vehicles, characteristics that most Express Lane evaluations continue to overlook.

3.3 Key Takeaway

Overall, the limited representation of freight in both government and academic evaluations demonstrates a critical methodological and knowledge gap. Although Express Lanes can meaningfully influence freight routing, travel time reliability, operational cost structures, and emissions outcomes, freight performance is rarely treated as a core evaluation metric. This reinforces the need for dedicated, freight-sensitive methodologies in future research and supports

the importance of the proposed study in advancing FDOT's understanding of Express Lane impacts on freight movement across Florida's strategic corridors.

4 Data Assessment

The purpose of this subtask is to assess the availability, completeness, and quality of datasets that can support a comprehensive evaluation of the targeted Express Lane facilities in Florida. These datasets must provide the necessary information to analyze facility performance across several key performance measures, including:

- Traffic Volume (Hourly/Daily/Annually, Classification, Days/Weeks, Peak/Non-Peak, Season, etc.)
- Travel Time (Average Travel Times, Travel Time Reliability, Peak/Non-Peak, Days/Weeks, Season, Value, etc.)
- Travel Speeds (Average Speed for Express Lanes and General-Purpose Lanes, Peak/Non-Peak, Days/Weeks, Season, etc.)
- Safety (Crash types, Rates/Frequencies, Severity (damage/injuries/fatalities), and Contributing Factors, etc.)
- Emissions (Value of Reductions, etc.)
- Fuel Consumption (Value of Savings, etc.)

In addition to meeting the above performance-measurement needs, the datasets must adequately cover the Express Lane facilities prioritized for analysis. These include the following list of active Express Lane corridors currently open to motorists across Florida:

- 295 Express East/West
- 595 Express
- 75 Express
- 95 Express
- 75 / Palmetto Express
- I-4 Ultimate
- Beachline Expressway
- Veterans Expressway

4.1 Overview of Available Datasets

In alignment with the project's scope of work and recognizing the substantial effort the State of Florida has invested in developing comprehensive, publicly accessible datasets, the research team prioritizes the use of FDOT-supported data sources that are available either freely or by formal request for academic and agency-funded projects. These datasets form the foundation of our evaluation framework and will be leveraged to the fullest extent possible. Should any performance measure require additional depth or resolution beyond what these sources provide, supplementary

third-party datasets (potentially fee-based) will be identified and recommended to address remaining gaps.

The remainder of this subchapter reviews each of the major free and/or publicly available datasets, summarizing their content, performance metrics, and relevance for assessing Express Lane facility impacts.

4.1.1 Florida Traffic Online

Florida Traffic Online is FDOT's primary statewide repository for historical traffic counts and roadway characteristics. Beyond standard AADT volumes, FTO provides direction-specific counts and detailed FHWA 13-class vehicle classifications, allowing analysts to distinguish passenger vehicles from freight-relevant truck categories. Because trucks account for the majority of ground-based freight deliveries, the availability of multi-year truck volume trends is especially important for assessing how EL facilities influence freight mobility.

For this project, FTO is particularly useful for:

- Establishing long-term volume baselines prior to EL implementation
- Evaluating pre/post changes in GP lane volumes adjacent to EL corridors
- Analyzing directional flow patterns and seasonal variability
- Tracking changes in freight activity (Classes 5–13) on EL-adjacent segments

Overall, FTO supports robust trend analysis across all targeted facilities and forms the backbone of historical demand assessment for EL impact studies.

4.1.2 FL511

FL511 is primarily designed as a real-time traveler information service, but the system archives operational events and travel time information that can be leveraged for performance evaluation. Key data elements include:

- Incident Information: crash events, lane closures, blocked lanes, and incident duration
- Corridor Travel Times: real-time and historical travel time information for major Florida corridors, including several with EL facilities
- Congestion Alerts: qualitative indicators of severe congestion or unusual delays

Although FL511 is not intended to function as a research-grade traffic database, its archived incident and travel time feeds can supplement other datasets such as NPMRDS or RITIS. In particular, FL511 can help validate incident timestamps, identify major disruptions that affect travel time reliability, and provide contextual understanding of unusual volume or speed patterns on EL and GP lanes.

4.1.3 MCSAW Freight Operations Exchange (FOX)

The Freight Operations eXchange (FOX) platform serves as a centralized data environment for monitoring and analyzing freight activity statewide. Managed jointly with Commercial Vehicle Operations (CVO) and Motor Carrier Size and Weight (MCSAW), FOX integrates weigh-in-motion (WIM) systems, axle sensors, and additional freight monitoring technologies.

FOX offers several freight-specific performance measures highly relevant to EL impact assessment, including:

- Truck Volume & Classification: precise axle-based truck counts, supporting identification of freight-related vehicle classes
- Truck Weights: gross vehicle weight, axle configurations, and load patterns
- Truck Speeds: lane-level spot-speed measurements for freight vehicles
- Freight Flow Monitoring: WIM time-of-day profiles useful for analyzing peak freight activity

These data can help quantify whether EL implementation influences freight routing, lane distribution, speed patterns, or temporal demand peaks.

4.1.4 National Performance Management Research Dataset (NPMRDS)

The National Performance Management Research Dataset (NPMRDS) is the primary federal dataset used for monitoring travel time reliability on the National Highway System. Developed by FHWA and provided at no cost to state DOTs through RITIS, NPMRDS offers high-resolution probe-based travel time data for both passenger vehicles and freight trucks.

Key performance measures available in NPMRDS include:

- Travel Time: 5-minute (and in some periods 1-minute) probe-based travel times
- Reliability Metrics:
  - Planning Time Index (PTI)
  - Buffer Index (BI)
  - Level of Travel Time Reliability (LOTTR), required for federal reporting
- Speed Profiles: Speeds derived directly from travel time feeds
- Separate Passenger and Truck Data: Dedicated truck probe streams allow freight-specific reliability analysis

Because RITIS provides the platform for extracting, visualizing, and downloading NPMRDS data, the research team has already initiated a RITIS account to streamline access. NPMRDS is especially valuable for assessing EL impacts on travel time reliability across both GP and EL corridors.

4.1.5 Florida Crash Analysis Reporting (CAR) System

The Florida Crash Analysis Reporting (CAR) System is the State Safety Office's authoritative repository for all police-reported crashes. Its depth and level of detail make it the foundational dataset for any safety evaluation on Florida's Express Lane corridors.

Performance measures available include:

- Crash Frequencies and Rates (per million VMT, per mile, per year)
- Crash Severity Breakdown: property damage only (PDO), injury, serious injury, and fatal crashes
- Crash Type Classification: rear-end, sideswipe, angle, single-vehicle, multi-vehicle, etc.
- Contributing Factors: weather, lighting, roadway geometry, human factors, etc.
- Location-Based Segmentation: GIS-coded crash coordinates enabling corridor segmentation and EL vs GP comparisons (where lane-level detail is available)

The CAR system is currently undergoing a major upgrade to integrate with the Signal 4 environment. Once fully merged, the system will provide faster processing, unified data access, and improved mapping and visualization tools, particularly for serious injury and fatal crashes. This upgrade will significantly enhance the ability to support before–after evaluations and Safety Performance Function (SPF) development.

4.1.6 SIGNAL 4 Analytics

SIGNAL 4 Analytics is one of Florida's most powerful crash analysis platforms, designed to provide highly accessible crash data with intuitive filtering, mapping, and visualization capabilities. Developed for FDOT and law enforcement partners, it supports extensive querying capabilities for in-depth safety analysis.

Performance measures and capabilities include:

- Crash Hot-Spot Identification: spatial clustering and density mapping
- Severity Analysis: detailed breakdown by injury level and fatal crashes
- Detailed Filtering: roadway type, vehicle classification (including heavy trucks), time-of-day, lighting, weather, behavior, and contributing factors
- GIS-Based Corridor Analysis: high-level spatial tools for before–after safety studies

Through FDOT's approval, the research team has secured access to Signal 4, enabling detailed safety evaluations across all Express Lane facilities. Signal 4's GIS-enabled environment will be especially valuable for lane-level or segment-level safety assessments, particularly when cross-referencing crash patterns with EL access points, merges, and buffer-separated segments.

4.1.7 Crash Modification Factors (CMF) Clearinghouse

The CMF Clearinghouse is not a raw data repository but a catalog of crash modification factors derived from national safety research. CMFs quantify the expected change in crash frequency

resulting from specific roadway treatments or design modifications. This resource is particularly valuable for scenario-based analysis, cost–benefit evaluations, and interpreting how geometric or operational changes to Els, such as buffer width, barrier type, or access configurations, may influence safety outcomes.

Key offerings include:

- Crash Modification Factors for geometric design features, separation treatments, barrier systems, rumble strips, and speed changes
- Peer-reviewed quality ratings for each CMF
- Documentation of study methods and applicability conditions

Although CMFs do not provide raw crash records, they are essential for supporting safety reasoning and forecasting the expected impact of EL design alternatives.

4.1.8 U.S. EPA MOVES (Motor Vehicle Emission Simulator)

MOVES is the national standard model for estimating emissions and fuel consumption from on-road vehicles. It supports project, link and network-level environmental analysis and is widely used in both research and agency evaluations.

Performance measures include:

- Emissions by pollutant: CO_2, NO_x, $PM_{2.5}$, VOCs, and others
- Fuel consumption estimates
- Speed- and operating-mode–dependent emission rates

MOVES becomes especially powerful when combined with speed and activity data from microsimulation (e.g., VISSIM) or probe-based datasets such as NPMRDS. This integration enables EL vs GP environmental comparisons, before–after evaluations, and sensitivity testing of tolling or operational strategies that may alter speed distributions.

4.1.9 Regional Integrated Transportation Information System (RITIS)

RITIS is one of the most powerful analytical tools available for this study. It aggregates real-time and archived data from multiple agencies and provides advanced visualization, performance dashboards, GIS mapping, and bulk-download capabilities. For Express Lane evaluation, its greatest relevance lies in hosting and processing the National Performance Management Research Dataset (NPMRDS).

Key available measures include:

- Travel times at 1-minute or 5-minute resolution
- Average speeds for all vehicles
- Truck-only speeds (critical for freight-specific reliability)
- Passenger-only speeds

- Automatically computed reliability metrics:
    - Buffer Index (BI),
    - Planning Time Index (PTI), etc.

RITIS enables:

- Direct EL vs GP speed and reliability comparisons
- Freight-only reliability assessment along major corridors
- Hourly, daily, seasonal, and incident-based profiling
- Large-scale before–after analysis through the Massive Data Downloader
- Easy GIS integration for corridor mapping and visualization

Given its freight-specific truck probe data and extensive reliability metrics, RITIS/NPMRDS will be one of the central datasets for evaluating EL performance in this project.

4.1.10 FDOT JustFOIA Portal

The FDOT JustFOIA Portal provides access to an extensive archive of statewide traffic monitoring datasets. These datasets offer a level of detail that is typically unavailable in public-facing platforms, making them highly valuable for reconstructing traffic demand patterns and supporting freight-specific analyses.

Data elements include:

- Annual Average Daily Traffic (AADT)
- Directional Volumes (daily, monthly, weekly)
- Vehicle Classifications (FHWA Classes 1–13 including trucks)
- Seasonal Adjustment Factors (weekly and monthly)
- Functional Classification (roadway type and characteristics)
- Peak-hour statistics (K-factors, D-factors, high-200-hour tables)
- Roadway Characteristics Inventory (RCI) attributes

Collectively, these datasets can be leveraged to support comprehensive analytical evaluation of Express Lane performance, such as:

- AADT + classification + directional volumes allow estimation of freight vs passenger flows
- K- and D-factors help quantify peak-hour congestion severity and directional demand
- Weekly/monthly seasonal factors enable normalization of traffic fluctuations
- Functional class and RCI attributes support segmentation of EL-adjacent GP lanes

Table 16. Dataset Coverage Across Key Performance Metrics

Dataset	Traffic Volume	Travel Time	Travel Time Reliability	Speed	Safety (Crash)	Emissions	Fuel Consumption
Florida Traffic Online (FTO)	✓	~		~			
FL511		✓	~		~ (incident logs)		
MCSAW / FOX WIM	✓ (truck counts)			✓			
NPMRDS		✓	✓	✓			
SIGNAL 4 Analytics					✓		
Crash Modification Factors Clearinghouse					~ (CMFs only)		
EPA MOVES						✓	✓
RITIS	~	✓	✓	✓	~ (incident overlays)		
FDOT JustFOIA Portal	✓ (AADT, hou rly, seasonal)						

Following the assessment of available datasets, the results have been consolidated into a comprehensive performance-metric matrix. Table 16 demonstrates that for every performance dimension required in this study, at least one suitable dataset exists. More specifically, in terms of traffic volume, FTO, MCSAW/FOX WIM, and the FDOT JustFOIA Portal provide robust multi-year counts and detailed vehicle classification, making them particularly valuable for freight-related analyses. For travel time and travel-time reliability, only NPMRDS and RITIS offer analytically rigorous measures such as BI, PTI, and LOTTR. With respect to speed data, NPMRDS, RITIS, and FOX WIM (for truck speeds) provide reliable speed profiles that can support both operational and freight-focused evaluations.

For safety analysis, Signal 4 Analytics offers one of the most comprehensive crash datasets, while the CMF Clearinghouse supports scenario-based reasoning through established Crash Modification Factors rather than raw crash data. In the environmental domain, EPA MOVES, when

supplied with externally derived speeds or volume inputs, can directly estimate emissions and fuel consumption. Finally, for freight-specific considerations, given that freight movement is strongly tied to heavy-vehicle activity, the most informative datasets include MCSAW/FOX WIM, NPMRDS truck-only probe data, JustFOIA vehicle classification, and FTO's truck percentage information.

Thus, we can infer that collectively, these datasets provide a strong, free of charge, foundation for evaluating the operational, safety, reliability, environmental, and freight-mobility impacts of Express Lane facilities in Florida.

4.2 Data Coverage by Facility

The goal of this subtask is to assess the extent and quality of data coverage for the recommended Express Lane facilities identified in the scope of work. Beyond simply confirming that data exist, it is essential to determine whether each dataset adequately supports before-and-after analyses, which are central to evaluating the impacts of Express Lane implementation. To do so, each facility must be examined individually with respect to its construction timeline, opening date, and availability of reliable operational data, ensuring that an appropriate evaluation timespan can be established for each corridor. This approach ensures that the selected datasets meaningfully align with the periods during which the facilities were accessible to motorists and can therefore support robust performance analysis.

4.2.1 Facility Overview

Each Express Lane facility has unique characteristics, particularly regarding its construction timeline, operational milestones, and implementation phases. To support a proper before-and-after evaluation, it is essential to understand when each facility was built, opened, and fully activated. Accordingly, this section presents a concise overview of the facilities identified in the scope of work as candidates for inclusion in the analysis.

4.2.1.1 295 Express East/West

I-295 in Jacksonville includes two distinct Express Lanes facilities, one on the West Beltway and one on the East Beltway, both located along the southern half of the regional beltway system. These managed toll lanes were designed to enhance corridor reliability, provide additional peak-period capacity, and improve traffic operations on one of Jacksonville's most heavily used commuter and freight corridors.

West Beltway Express Lanes

- Limits: I-95 (near The Avenues) ⇄ Buckman Bridge
- Construction Timeline:
  - Began July 2014;
  - Opened to traffic May 18, 2019
- Length: Approximately 4.5 miles

- Configuration: One 12-ft Express Lane in each direction, added between I-95 and the Buckman Bridge

East Beltway Express Lanes

- Limits: SR 9B (future I-795) ⇄ J. Turner Butler Boulevard (SR 202)
- Construction Timeline:
  - Construction from 2016–2019
  - Opened in phases during Fall 2020–2021 and fully operational by April 9, 2022
- Length: Approximately 5 miles
- Configuration: Two 12-ft Express Lanes in each direction, including noise walls and stormwater improvements.

4.2.1.2 595 Express

The 595 Express project is one of Florida's most significant reversible managed-lane facilities, designed to improve mobility along the SR 595 corridor between I-75/Sawgrass Expressway and east of SR 7, with a direct connection into the median of Florida's Turnpike. A central feature of the project is the construction of three at-grade reversible Express Lanes, collectively known as 595 Express, which operate with variable tolling to maintain optimal traffic flow.

The lanes reverse direction based on peak travel patterns, eastbound during the morning peak and westbound during the afternoon peak, providing dedicated, high-reliability capacity for commuters and regional travelers. Each lane is 12 feet wide, with 10-foot shoulders on both sides for enhanced safety and incident management.

Use of the Express Lanes is restricted to two-axle vehicles, and all users must have a SunPass transponder linked to a pre-paid account. No cash or toll-by-plate options are permitted, ensuring uninterrupted, free-flow tolling operations.

Construction Timeline:

- Construction of 595 Express began in June 2009,
- The system reached substantial completion on March 26, 2014, marking the full opening of the reversible facility.

4.2.1.3 75 Express

The 75 Express project represents a major segment of the South Florida Express Lanes Network, providing managed-lane capacity along one of the region's most heavily traveled commuter and freight corridors.

Construction Timeline:

- Construction period that began in early 2014.
- Officially opened 75 Express to motorists on March 24, 2018.

The project introduces approximately 15 miles of tolled Express Lanes along I-75, extending from I-595 in Broward County to NW 170th Street in Miami-Dade County. The facility consists of four barrier-separated, tolled managed lanes located in the median, supported by Intelligent Transportation System (ITS) infrastructure and designed to accommodate future express bus services.

Within Miami-Dade County, the overall Express Lanes system comprises 13 miles distributed across two interconnected limited-access corridors:

- Approximately 10 miles constructed along SR 826 (Palmetto Expressway)
- Approximately 3 miles constructed along SR 93 (I-75).

4.2.1.4 95 Express

The 95 Express facility is one of FDOT's earliest and most significant managed lanes projects, implemented to improve mobility, enhance travel-time reliability, and manage congestion along one of Florida's busiest commuter and freight corridors. The initiative began as a pilot project in 2008 within Miami-Dade County and has since expanded northward into Broward County as part of a multi-phase program. More specifically:

- Phase 1A, opened in December 2008, introduced the first segment of northbound Express Lanes along a 7-mile stretch of I-95, extending from south of SR 112/I-195 to the Golden Glades Interchange near NW 151st Street.
- Phase 1B, launched in January 2010, added the corresponding southbound Express Lanes between Florida's Turnpike and north of SR 836 (Dolphin Expressway).
- Phase 2, delivered through a design-build contract from late 2011 to October 2016, extended Express Lanes in both directions from Florida's Turnpike to Broward Boulevard. This phase converted former HOV lanes into two dynamically priced Express Lanes in each direction, expanding capacity and improving corridor operations.
- Phase 3 began construction in mid-2016, with the first segment completed in late 2019. Subsequent segments continued construction between 2018 and 2023, supporting the long-term vision to extend managed-lane operations north toward Palm Beach County.

Today, 95 Express spans approximately 21 miles, from SR 836/I-395 near downtown Miami to Broward Boulevard in Fort Lauderdale. The facility operates as a dynamically priced system, allowing single-occupancy vehicles (SOVs) to access the lanes while maintaining a minimum operating speed of 45 mph, consistent with FDOT's performance objectives. The Express Lanes were developed by converting the existing HOV system and now serve as a critical part of Southeast Florida's regional mobility network.

4.2.1.5 75 / Palmetto Express

The 75 / Palmetto Express project introduces managed tolled lanes along two major corridors in Miami-Dade County, SR 826 (Palmetto Expressway) and I-75 (SR 93), with the goal of improving mobility, enhancing travel-time reliability, and reducing congestion on two of South Florida's most

heavily traveled freeways. The project spans approximately 13 miles, extending from Flagler Street to NW 154th Street on the Palmetto Expressway and from NW 154th Street to NW 170th Street along I-75. It also provides operational continuity with the I-75 Express Lanes extending north into Broward County toward I-595.

Along the Palmetto Expressway segment, the project constructed one to two tolled Express Lanes in each direction, depending on the specific segment. Along I-75, one tolled Express Lane in each direction was added within the median, forming a continuous managed-lane system linking to the broader South Florida Express Lanes network.

Construction Timeline:

- Construction began in January 2014 and
- Officially opened to traffic on March 24, 2018, initiating Express Lane toll operations and providing a new premium travel option through northern Miami-Dade County.

4.2.1.6 I-4 Ultimate

The I-4 Ultimate project represents the most extensive highway infrastructure initiative in Florida's history. Spanning 21 miles of Interstate 4 (I-4) from west of Kirkman Road (SR 435) to east of SR 434, the project delivered a complete reconstruction of the corridor within the existing right-of-way, alongside major safety, operational, and capacity enhancements.

A central component of the project is the addition of two tolled, managed lanes in each direction, known as I-4 Express. These lanes were designed to provide reliable travel-time options through one of the busiest and most congested freeway segments in Central Florida.

Construction Timeline:

- I-4 Ultimate construction began in February 2015, marking the start of the largest highway reconstruction project in Florida's history.
- The reconstructed corridor—including the new I-4 Express Lanes—officially opened to traffic on February 26, 2022.

During the initial rollout, tolls were assessed using a flat, per-segment pricing structure (e.g., $0.50 per segment) as part of an introductory period. FDOT has since announced that dynamic pricing, a real-time tolling strategy that adjusts based on traffic demand and operating conditions, began on February 24, 2025, fully transitioning the facility to a managed-lane operation consistent with other Express Lane corridors statewide.

4.2.1.7 Beachline Expressway

The SR 528 (Beachline Expressway) improvement project introduced managed toll lanes along a key segment of Orlando's regional expressway network. The widening from I-4 to Florida's Turnpike added two inside express toll lanes, one in each direction, along a 4.3-mile section

between I-4 and the Turnpike, together with an additional auxiliary lane in each direction to enhance merging and weaving operations.

Overall, the Beachline Expressway now operates with two managed lanes in each direction for approximately 8 miles, extending from McCoy Road to I-4.

Construction Timeline:

- The express lanes between Florida's Turnpike and I-4 opened to motorists in July 2019, followed by the segment from McCoy Road to the Turnpike in May 2020.

Vehicle eligibility is limited to two-axle vehicles equipped with an active SunPass or interoperable transponder. Trucks with three or more axles are prohibited from using the express lanes, while transit buses, school buses, and registered vanpools are permitted. The facility uses double-skip striping for lane separation, providing visual delineation while maintaining operational flexibility at designated access zones.

4.2.1.8 Veterans Expressway

The Veterans Expressway (SR 568) in Tampa includes one managed lane in each direction over approximately 9 miles, extending from Memorial Highway to north of Hutchison Road. The facility is part of the Tampa-area managed lanes network and was implemented to improve corridor mobility and peak-period travel time reliability.

Construction Timeline:

- Construction for the widening and express lanes conversion began in May 2013
- The Veterans Expressway managed lanes fully opened to traffic in May 2018.

Vehicle eligibility is limited to two-axle vehicles; trucks with three or more axles are not permitted to use the managed lanes. All users must have an active SunPass or interoperable transponder. Tolling is applied through the standard tolling system used on the roadway, general toll customers pay the same toll rates charged for the adjacent non-managed lanes, as this facility operates without a separate dynamic pricing structure.

Table 17. Data Availability by Express Lane Facility

Facility / Dataset	FTO	FL511	MCSAW / FOX WIM	NPMRDS	Signal 4	CMF Clearinghouse	EPA MOVES	RITIS	JustFOIA
295 Express	✓	✓	✓	✓	✓			✓	✓
595 Express	✓	✓	✓	✓	✓			✓	✓
75 Express	✓	✓	✓	✓	✓			✓	✓
95 Express	✓	✓	✓	✓	✓			✓	✓
75/Palmetto Express	✓	✓	✓	✓	✓			✓	✓
I-4 Ultimate Express	✓	✓	(✓)*	✓	✓			✓	✓

Table 17. Data Availability by Express Lane Facility (continued)

Facility / Dataset	FTO	FL511	MCSAW / FOX WIM	NPMRDS	Signal 4	CMF Clearinghouse	EPA MOVES	RITIS	JustFOIA
Beachline Expressway	✓	✓	(✓)*	✓	✓			✓	✓
Veterans Expressway	✓	✓	✓	✓	✓			✓	✓

Results presented in Table 17 indicate that most publicly available, no-cost datasets provide statewide coverage. This suggests that obtaining the required data for all Express Lane facilities under consideration should not present significant challenges. However, two important clarifications must be noted.

First, regarding the rationale for potential differences in FOX WIM coverage: the Freight Operations eXchange (FOX) platform relies heavily on data from FDOT's Weigh-in-Motion (WIM) stations and Commercial Vehicle Operations (CVO) infrastructure. Because WIM stations are not uniformly distributed across the state, the availability of freight-specific metrics is corridor-dependent. Coverage is expected to be strongest along I-75, I-95, the Palmetto Expressway, and I-295, where WIM density is highest. In contrast, although I-4 and SR-528 carry substantial freight volumes, these corridors have comparatively fewer WIM stations, and existing sites are often located farther from the Express Lane segments. As a result, axle-weight data, truck classifications, and freight-specific speed profiles may be less complete for these facilities. Please note, that this interpretation is based on the general distribution of WIM sites in Florida and should be verified during subsequent data acquisition efforts.

Second, it is important to emphasize that the Crash Modification Factors (CMF) Clearinghouse does not provide site-specific datasets. Instead, it offers crash modification factors that can be applied generically across facilities for scenario-based evaluations. Similarly, the EPA MOVES model does not provide facility-specific data by itself; rather, it requires external inputs, such as speeds, volumes, and fleet composition, derived from other datasets. Therefore, MOVES outputs will depend entirely on the quality and completeness of the underlying input data rather than any inherent difference in facility coverage.

4.3 Data Assessment Limitations

A key limitation in the current stage of the data assessment is the lack of direct access to the MCSAW/FOX WIM platform. Although the FOX system is central to understanding freight activity, providing truck weights, classifications, and freight-specific speed profiles, our team has been unable to obtain login credentials despite multiple outreach attempts. Initial inquiries were routed to two HNTB representatives involved in the platform's development; however, one email address appears to be deactivated (FDOT associated email address), and the other contact has not responded. As a result, all FOX-related assessments in this report rely solely on secondary

information gathered through available documentation rather than hands-on system access. This limitation may affect the precision of our freight data evaluation, and securing formal access remains a priority for subsequent project phases.

4.4 Data Assessment Takeaway

Overall, the dataset assessment indicates that Florida's statewide data infrastructure provides strong coverage for nearly all performance metrics needed to evaluate EL impacts, including volumes, speeds, travel time reliability, and safety, across all facilities under consideration. With statewide datasets such as FTO, NPMRDS/RITIS, Signal 4, and the JustFOIA traffic archives, baseline and before–after analyses are fully feasible for every corridor. However, an important limitation remains the current lack of direct access to the MCSAW/FOX WIM platform, which restricts the research team's ability to fully assess freight-specific metrics such as axle-based classifications, gross vehicle weights, and truck-only speed profiles. Because FOX is the only state-managed platform that consolidates WIM and Commercial Vehicle Operations (CVO) data, temporary reliance on secondary documentation introduces some uncertainty regarding freight coverage. To mitigate this constraint, the research team has already initiated communication with third-party private-sector data providers as potential alternatives should access challenges with FOX persist. Despite this limitation, the broader data ecosystem should be considered sufficiently robust to support the project's core analytical objectives.

Part II

Empirical Analysis of Express-Lane Impacts

Before-and-After Performance Analysis: I-4, I-95, and I-295 Express Corridors

Part II presents the empirical before-and-after analysis conducted as Deliverable 2. Building on the literature and data review in Part I, this analysis applies RITIS travel-time and speed data and FDOT traffic-count records to quantify the performance impacts of express-lane implementation on three Florida SIS corridors: I-4 Ultimate (SR-400), I-95 Express (SR-9), and I-295 Express East/West (SR-9A).

1 Introduction

1.1 Freight volume and economic value in the state of Florida

Freight transportation is a cornerstone of the United States' economic prosperity and is inextricably linked to the performance of the roadway system. Despite ongoing investments in multimodal freight transportation, including air cargo, maritime shipping, and rail, road transportation remains the dominant mode for freight movement and is expected to further increase its market share in the coming decades. According to recent forecasts, by 2045 truck freight traffic in the United States is projected to increase by approximately 30 percent by tonnage and 60 percent by value, accounting for nearly 65 percent of total freight ton-kilometers. In 2020, trucks carried 72.5 percent of domestic freight by weight and accounted for 80.4 percent of the national freight bill, underscoring the central role of trucking in the U.S. freight system (TRIP, 2023).

At the state level, Florida represents a particularly freight-intensive economy. In 2022 alone, Florida's freight system moved approximately 839 million tons of goods valued at $1.1 trillion, ranking eighth among all U.S. states in terms of total freight value, as illustrated in Figure 6. Projections by Short & Leslie (2023) indicate that, between 2022 and 2050, freight moved by trucks in Florida is expected to increase by 94 percent in value (in inflation-adjusted dollars) and by 58 percent in weight. Further highlighting the importance of the trucking industry, trucks, which essentially includes the concepts of long-haul and drayage operations, account for approximately nine percent of total vehicle travel on Florida's Interstate highways and 16 percent of travel on rural Interstate facilities. These trends emphasize the growing dependence of Florida's economy on efficient and reliable truck-based freight movement.

RANK	2022 Freight Shipped by Value All Modes (millions of dollars)	
1	Texas	3,132,697
2	California	2,845,127
3	Illinois	1,571,188
4	New York	1,338,798
5	Pennsylvania	1,137,664
6	Michigan	1,090,656
7	Ohio	1,085,222
8	Florida	1,064,559
9	New Jersey	996,118
10	Georgia	985,880

Figure 6. Freight Shipped by Value All Modes (TRIP, 2023)

1.2 Florida's Strategic Location

Florida's heightened focus on freight mobility is largely driven by the state's geostrategic location at the convergence of major north–south and east–west trade corridors. This positioning has established Florida as a critical gateway for U.S. trade with Latin America and Caribbean nations, regions that have contributed to particular growth in e-commerce, distribution activity, and industrial production. As a result, Florida hosts a dense concentration of freight gateways, including seaports and airports, that play a pivotal role in facilitating international and domestic trade flows.

Currently, in the State of Florida there are 16 public deepwater seaports, which support extensive maritime activity and strengthen the state's economic ties with South America and the Caribbean. These ports act as major engines of economic development for local communities, serving as catalysts for job creation, trade expansion, and regional investment, and ultimately contributing to the state's overall prosperity and social welfare. According to the Florida Seaport Transportation and Economic Development (FSTED, 2025), freight-related activities generated by intermodal transportation operations, linking maritime facilities with inland markets through the trucking and rail systems, support nearly 1.2 million jobs and generate more than $195 billion in total economic value. This contribution represents approximately 12.2 percent of Florida's $1.6 trillion gross domestic product. When freight-dependent industries are considered, the top five such sectors alone account for approximately 30.5 percent of Florida's GDP. These impacts continue to grow as a result of sustained investments in port and intermodal infrastructure aimed at increasing operational efficiency and capacity for both cargo and cruise activities. Since 2015, Florida's seaports have experienced a 20.4 percent increase in cargo volumes, further reinforcing the critical

role of freight transportation, and its associated highway and intermodal connections, in supporting Florida's economic competitiveness.

1.2.1 Port Tampa Bay

Port Tampa Bay is one of Florida's major seaports and a critical freight gateway for the Tampa Bay region. The port contributes significantly to the regional economy by attracting manufacturing, distribution, and logistics firms that locate nearby to reduce transportation costs and improve supply chain efficiency. By minimizing drayage distances from the port, importers and exporters benefit from lower trucking costs, faster delivery times, and reduced carbon emissions. As a result, industries such as retail, e-commerce, food and beverage, and manufacturing increasingly rely on Port Tampa Bay to support growing demand for same-day service and tighter delivery windows.

Strategically positioned along the I-4 Corridor, which is home to nearly half of Florida's 23 million residents and serves the majority of the state's 146 million annual visitors (www.porttb.com), Port Tampa Bay represents a vital asset to Florida's largest concentration of distribution centers. The Tampa–Orlando I-4 Corridor enables multiple daily round-trip truck deliveries from the port, offering a competitive advantage compared to traditional routings through congested out-of-state ports. In addition, favorable northbound backhaul trucking rates extend the port's reach beyond Florida to customers throughout the southeastern United States.

1.2.2 Port Everglades

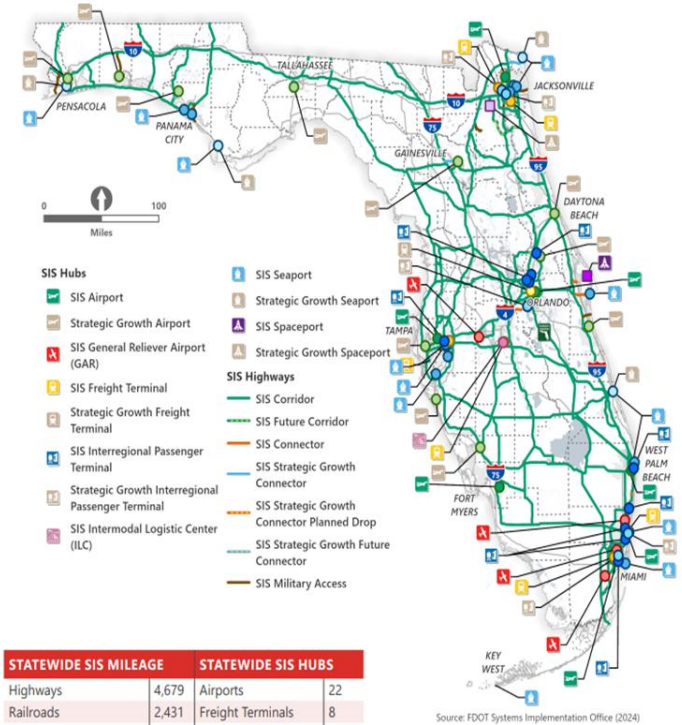
Port Everglades is a major economic engine for Broward County and a critical component of Florida's freight and passenger transportation system. Its significance stems from a highly diversified business portfolio, as the port supports both cargo and cruise operations. In addition to being the third-busiest cruise homeport in the world, Port Everglades is one of Florida's leading container ports and ranks among the most active cargo ports in the United States. The port also serves as South Florida's primary seaport for the receipt and distribution of energy products, including gasoline and jet fuel, underscoring its strategic importance to regional energy security.

Port Everglades offers exceptional multimodal connectivity that enhances its competitiveness and reach. Port users benefit from direct access to the Interstate Highway System via I-95, proximity to an international airport located within two miles of the port, and advanced Foreign Trade Zone warehousing facilities. In addition, the port operates a 43-acre international and domestic intermodal container transfer facility, enabling efficient cargo movement to major inland markets. Through these intermodal connections, freight shipped through Port Everglades can reach key distribution centers in Atlanta and Charlotte within two days and access approximately 70 percent of the U.S. population within four days (Martin Associates, 2025).

1.2.3 Port of Miami

Staying in South Florida, PortMiami stands as one of the two largest economic powerhouses in Miami-Dade County and a critical gateway for international trade. The port's operations generate an estimated annual economic impact of $61.4 billion and support approximately 340,078 jobs, highlighting its substantial regional, national, and global significance. PortMiami operates as a landlord port, is located in close proximity to Florida's I-95 corridor, and maintains partnerships with more than 20 cruise line companies. In addition, containerized cargo operations at the port are handled by three major shipping lines, including all five of the world's largest international shipping companies.

PortMiami has strong trade relationships with key global markets, with cargo flows primarily linked to Latin America and the Caribbean (48 percent), Asia (31 percent), and Europe (20 percent). The port is Florida's leading international cargo gateway and one of the state's busiest ports for perishable goods. In fiscal year 2024, PortMiami handled approximately 1,089,443 twenty-foot equivalent units (TEUs), ranking 11th nationally in container volume and first in Florida for international containerized cargo. These characteristics underscore PortMiami's vital role in supporting time-sensitive supply chains and reinforcing Florida's position within global freight networks (www.miamidade.gov). Figure 7 shows Florida's statewide freight infrastructure.



STATEWIDE SIS MILEAGE		STATEWIDE SIS HUBS	
Highways	4,679	Airports	22
Railroads	2,431	Freight Terminals	8
Waterways	1,079	Intermodal Logistic Centers	1
		Seaports	12
		Spaceports	2

Figure 7. Florida's Statewide Freight Infrastructure (FDOT Systems Implementation Office, 2024)

In addition to seaports, airports constitute a critical component of Florida's intermodal freight transportation system and, in coordination with the trucking sector, generate substantial economic activity across the state. Airports complement Florida's Interstate freight corridors by serving as air cargo gateways with direct surface access for truck movements, enabling efficient connections between long-distance domestic and international markets and inland distribution centers. Florida's aviation system comprises more than 125 public-use airports, including 19 primary commercial service airports extending from the Panhandle to the Florida Keys. Collectively, Florida's airports function as major economic hubs, directly employing more than 18,000 people and supporting over 5,000 on-airport businesses. Beyond direct employment, Florida's airports play a vital role in facilitating air cargo services that link global supply chains with Florida-based industries, reinforcing the state's position as a global business hub. When trade-related users and downstream economic effects are considered, air freight–related activities in Florida support approximately 625,410 jobs, representing about 5.8 percent of the state's 10.8 million total jobs (FDOT, 2022b).

1.2.4 Miami International Airport (MIA)

Miami International Airport (MIA) is located approximately five miles west of the Port of Miami and is directly connected to a dense network of expressways and Interstate highways, including I-395, I-195, and I-95. This strategic location enables efficient intermodal connectivity between air cargo operations, seaports, and Florida's primary freight corridors. MIA is the busiest airport in the United States for international freight and the second busiest for international passenger traffic, offering more flights to Latin America and the Caribbean than any other U.S. airport.

MIA also serves as a major economic engine for Miami-Dade County and the State of Florida. The airport generates an estimated $181.4 billion in annual business revenue and facilitates approximately 60 percent of all international visitors to Florida (www.miami-airport.com). In addition, MIA and its associated aviation industries support approximately 843,000 direct, indirect, induced, and related jobs, underscoring the airport's substantial regional, national, and global economic influence.

1.2.5 Fort Lauderdale–Hollywood International Airport (FLL)

Fort Lauderdale–Hollywood International Airport (FLL) is located in Southeast Florida, approximately two miles west of the Atlantic coastline, in the heart of Broward County and adjacent to Port Everglades. The airport is served by a dense network of U.S. highways and Interstate facilities, including I-595 and I-95, both of which operate Express Lane facilities and form part of Florida's major managed-lane corridor system. Local roadway connections further integrate the airport with these primary freight and passenger corridors, supporting efficient surface access for both passenger and cargo movements.

FLL functions as a major aviation hub in South Florida, serving approximately 35.2 million passengers in 2024, representing a 0.3 percent increase compared to 2023. This level of activity

places FLL among the top 20 busiest airports in the United States, reinforcing its role as a critical multimodal node with strong connections to Florida's Interstate and Express Lane networks. However, in 2025 FLL served 32.2 million passengers, down 8.5% from 2024 (www.broward.org/Airport).

1.2.6 Tampa International Airport (TPA)

Tampa International Airport (TPA) is located in the heart of the Tampa Bay region, less than one mile from the harbor and approximately five miles west of downtown Tampa. The airport is directly accessed via major Interstate corridors, including I-275 and I-4, providing strong connectivity to the regional freight and passenger transportation network. TPA is a major economic contributor to West Florida, supporting more than 10,000 jobs through airport operations and affiliated business partners.

The Hillsborough County Aviation Authority reported revenues exceeding $381 million in fiscal year 2023. This growth continued into fiscal year 2025, when airport revenues reached $486.2 million, representing a $58.3 million increase compared to fiscal year 2024 (www.tampaairport.com).

1.2.7 Orlando International Airport (MCO)

Orlando International Airport (MCO) is the primary international airport serving Central Florida and is located approximately six miles southeast of downtown Orlando, in close proximity to the I-4 corridor. Ranked as the seventh busiest airport in the United States and the busiest in Florida, MCO is served by dozens of passenger airlines and provides nonstop flights to more than 160 destinations worldwide. As the principal gateway to Central Florida's major tourism, entertainment, and business centers, the airport plays a critical role in supporting the state's economy.

MCO generates an estimated economic impact exceeding $41 billion annually and functions as a world-class global connector, serving millions of passengers each year across its three passenger terminals. In addition to its aviation operations, Orlando International Airport is distinguished as the only airport in the United States with an integrated intermodal facility that offers high-speed rail service, further strengthening its connectivity to regional and statewide transportation networks (www.flymco.com).

1.2.8 Jacksonville International Airport (JAX)

Jacksonville International Airport (JAX) is located approximately 15 minutes from downtown Jacksonville and provides nonstop service to major U.S. cities, including several international gateway airports. The airport serves more than 7 million passengers annually and recorded its busiest year on record in 2024, handling over 7.6 million passengers, representing a 2.8 percent increase compared to the previous 2023 record of 7.4 million passengers.

JAX benefits from direct access to major Interstate facilities, including I-95 and I-295, which integrate the airport into Florida's primary north–south and regional freight corridors (www.flyjacksonville.com).

1.3 Impact of Congested Highways

The scale and intensity of activity generated by Florida's major airports and seaports highlight the substantial number of trips required to move both goods and people. Intermodal transportation plays a critical role in supporting these movements, as freight gateways are strategically located with direct access to key Interstate facilities that facilitate efficient cargo and passenger flows. However, the growing demand associated with these facilities places increasing pressure on roadway infrastructure, which must accommodate both freight and commuter traffic.

Despite ongoing planning efforts, capacity expansion projects, and the implementation of traffic mitigation strategies, congestion continues to occur, particularly during peak travel periods and under nonrecurring conditions such as incidents, weather events, or work zones. This congestion is not only a challenge for daily commuters but also has significant implications for freight mobility and regional economic performance. Delays on congested highways increase operating costs for trucking, reduce travel time reliability, and can disrupt time-sensitive supply chains (FDOT, 2007). As a result, understanding and quantifying the costs associated with highway congestion is essential for evaluating transportation strategies aimed at improving system efficiency and supporting economic competitiveness.

One of the most direct externalities associated with roadway congestion is its impact on road safety, particularly in corridors with high truck volumes. Congested conditions often limit trucks' ability to maintain safe following distances, increasing the likelihood of crashes and secondary incidents. In freight-intensive and operationally fragmented corridors, such incidents can trigger recurring disruptions, affecting not only the vehicles directly involved but also freight movements delayed as a result of lane blockages and traffic queues. These disruptions can significantly affect delivery reliability and supply chain performance (Leslie & Murray, 2025).

Safety data illustrate the magnitude of this issue. Between 2017 and 2021, an average of 336 people were killed annually in Florida in crashes involving large trucks, corresponding to approximately 15 fatalities per 100 million population. Over the same period, fatalities in large-truck-involved crashes nationwide increased by 18 percent, rising from 4,906 to 5,788 (Short & Leslie, 2024). Notably, approximately five out of six people killed in crashes involving large trucks were occupants of other vehicles or vulnerable road users, such as pedestrians or bicyclists. While large trucks account for roughly five percent of registered vehicles and about ten percent of total vehicle miles traveled annually, they are involved in approximately 13 percent of all traffic fatalities. The most common contributing factor in fatal crashes between large trucks and other vehicles is the lane entry of the non-truck vehicle into the truck's lane, a behavior that is often exacerbated under congested conditions.

2022 Rank	State	Statewide Costs 2021	Statewide Costs 2022	Percent Change	2021 Rank
1	Texas	$7,256,430,452	$9,171,520,948	26.40%	2
2	California	$9,000,397,702	$8,774,467,001	-2.50%	1
3	Florida	$7,157,229,169	$8,437,202,215	17.90%	3
4	New York	$4,917,126,628	$5,795,489,531	17.90%	4
5	Georgia	$4,021,578,225	$4,638,414,469	15.30%	6
6	New Jersey	$3,838,944,444	$4,424,571,565	15.30%	7
7	Illinois	$3,379,889,793	$4,315,102,629	27.70%	8
8	Pennsylvania	$3,268,381,038	$3,705,348,642	13.40%	9
9	Louisiana	$4,217,050,404	$3,680,837,351	-12.72%	5
10	Tennessee	$3,154,354,178	$3,613,265,679	14.50%	10

Figure 8. Statewide Congestion Cost (TRIP, 2023)

Beyond safety impacts, congestion imposes substantial economic costs on freight mobility. Congestion levels in Florida are sufficiently severe that the state consistently ranks among the worst in the nation. Statistics presented in **Figure 8** with congestion-related costs to the trucking industry exceeding $7.1 billion annually. Further evidence of this trend is shown in **Figure 9**, which indicates that two Florida metropolitan areas, Orlando and Jacksonville, experienced some of the fastest-growing congestion costs in the United States. In both regions, rising congestion was closely associated with increased truck activity. This growth in truck volumes coincided with a 16 percent year-over-year increase in the value of shipments of vegetables, melons, and berries, Florida's largest agricultural produce category, highlighting the direct linkage between freight demand growth and congestion pressures.

As freight demand continues to grow, these conditions place additional stress on roadway infrastructure, leading to increased fuel consumption, longer travel times, and delayed deliveries. In 2022 alone, traffic congestion resulted in approximately $94.6 billion in additional operational costs to the U.S. trucking industry, driven by commercial trucks spending an estimated 1.3 billion hours stuck in traffic. More broadly, U.S. business logistics costs reached $2.3 trillion in 2022, representing 9.1 percent of national gross domestic product, which constitutes the highest share ever recorded (TRIP, 2023). At the national level, congestion cost increases are driven primarily by higher operational costs borne by the trucking industry. In 2022, the four states with the highest congestion-related costs were Texas, California, Florida, and New York, respectively. Collectively, these states accounted for approximately 29.6 percent of total national congestion costs. These findings underscore the outsized role that Florida plays in national freight congestion and reinforce

the need for targeted strategies to improve freight mobility and system reliability on the state's most critical corridors.

Metro Area	Statewide Costs 2021	Statewide Costs 2022	Percent Change	Annualized Rate of Increase 2016-2022
New Orleans, LA Metro	$632,035,596	$866,727,792	37.13%	9.37%
Buffalo, NY Metro	$322,063,522	$414,260,620	28.63%	3.84%
El Paso, TX Metro	$331,349,540	$423,579,733	27.83%	10.89%
Orlando, FL Metro	$713,652,821	$911,251,015	27.69%	8.48%
Tulsa, OK Metro	$92,024,449	$115,554,066	25.57%	4.14%
Knoxville, TN Metro	$435,968,529	$545,447,099	25.11%	10.12%
Jacksonville, FL Metro	$427,766,884	$531,794,468	24.32%	8.48%
Phoenix, AZ Metro	$300,316,710	$370,590,072	23.40%	9.95%
Chicago, IL Metro	$2,570,539,181	$3,143,215,804	22.28%	6.33%
Miami, FL Metro	$2,618,229,310	$3,199,518,010	22.20%	7.12%

Figure 9. US Metro Areas - Congestion Cost (TRIP, 2023)

The aforementioned discussion and supporting statistics highlight the substantial impact that traffic congestion has on the U.S. economy, largely stemming from disruptions to global supply chains and delays within the trucking industry in particular. With respect to freight mobility, congestion impedes truck operations and contributes to inflationary pressures by increasing the cost of moving goods and, ultimately, the prices of goods and services. Mitigating these impacts requires a clear understanding of the magnitude and sources of congestion-related externalities.

To support effective congestion management and investment decisions, transportation planners and traffic engineers must be able to quantify the economic costs associated with freight delays. Accordingly, the cost of congestion to the trucking industry is commonly estimated using three primary data inputs (Leslie & Murray, 2025).

1. The first is average speed, as observed highway speeds for combination trucks, segmented by geography and time of day, are used to quantify deviations from free-flow conditions and the resulting additional travel time.
2. The second input is truck volume or vehicle miles traveled (VMT), which captures the number of trucks affected by congestion across specific corridors, regions, or time periods. Truck VMT represents the total distance traveled by trucks over a given timeframe and can be disaggregated by metropolitan area, state, or region.
3. The third input is operational costs, expressed as the marginal cost per hour to operate a Class 7/8 combination truck. When multiplied by the estimated hours of delay, this cost yields the total congestion-related economic impact for a given location.

2 Conduct Empirical Analysis

This section presents the empirical analysis conducted to evaluate the operational performance and freight-related impacts of the selected Express Lane corridors. Using observed traffic and safety data from RITIS and FDOT-supported sources, the analysis examines traffic volumes, travel times, delays, reliability, and crash patterns before and after Express Lane implementation. The objective is to quantify corridor-level performance changes and assess the extent to which Express Lanes influence congestion, reliability, and freight mobility under real-world operating conditions.

2.1 Selection of Study Cases

For the purposes of this section, the research team should evaluate the existing Express Lane facilities in Florida to identify the most appropriate candidates for detailed analysis. This evaluation considers multiple criteria, including freight traffic volumes, geographic relevance to major freight hubs, variability in traffic patterns, data availability and quality, policy and regulatory constraints, and stakeholder interest. By systematically assessing each facility against these factors, the research team aims to ensure that the selected corridors are both representative of Florida's freight system and supported by sufficient data to enable robust, policy-relevant analysis of Express Lane impacts.

2.1.1 Freight Relevance

The primary criterion for identifying candidate Express Lane facilities in Florida is their significance to freight mobility. In particular, the geographic location of these facilities relative to major freight generators, such as seaports, airports, intermodal terminals, and distribution centers, is critical, as Express Lane performance in these areas can directly influence freight efficiency and reliability. To support a data-driven selection process, the research team analyzed truck volume data for the facilities under consideration to provide quantitative evidence of freight activity and inform corridor prioritization.

The results, presented in **Figure 10**, illustrate the variation in Annual Average Daily Truck Traffic (TruckAADT) across the evaluated facilities, based on data obtained from the FDOT Open Data Hub, integrating sing the most recently available dataset at the time of analysis (2024). The findings indicate that the South Florida segment of the I-95 Express Lanes exhibits the highest maximum TruckAADT by a substantial margin, as well as the highest mean TruckAADT. This pattern reflects sustained, systemwide freight usage rather than isolated high-volume segments. The second strongest candidate is the I-295 Express East/West corridor, which demonstrates the second-highest mean TruckAADT along with very high maximum values, indicating significant freight circulation. Closely following is the I-4 corridor (SR 400 / I-4 Ultimate), which exhibits mean TruckAADT values nearly identical to those observed on I-295 and similarly high maximum values.

Notable truck activity is also observed along the I-75/Palmetto Expressway corridor, where high mean and maximum TruckAADT values reflect intense urban and local freight movement.

However, this facility does not operate Express Lanes and therefore is less suitable for inclusion in the current analysis. For the remaining evaluated facilities, truck traffic volumes are substantially lower, indicating more limited freight relevance.

Based solely on truck volume metrics, the results clearly identify I-95 as Florida's primary long-haul and regional freight spine, serving major ports, airports, and distribution centers. From a freight mobility perspective, this corridor emerges as the leading candidate for advancement to the next stage of analysis. Similarly, the results underscore the freight importance of I-295, which functions not merely as a commuter beltway but as a critical corridor supporting heavy freight circulation associated with JAXPORT, rail facilities, and regional distribution networks. In addition, I-4 stands out as a strong candidate, as its freight significance is driven not only by volume but also by pronounced variability, congestion exposure, and reliability challenges, making it particularly well suited for evaluating the impacts of Express Lane operations on freight movement.

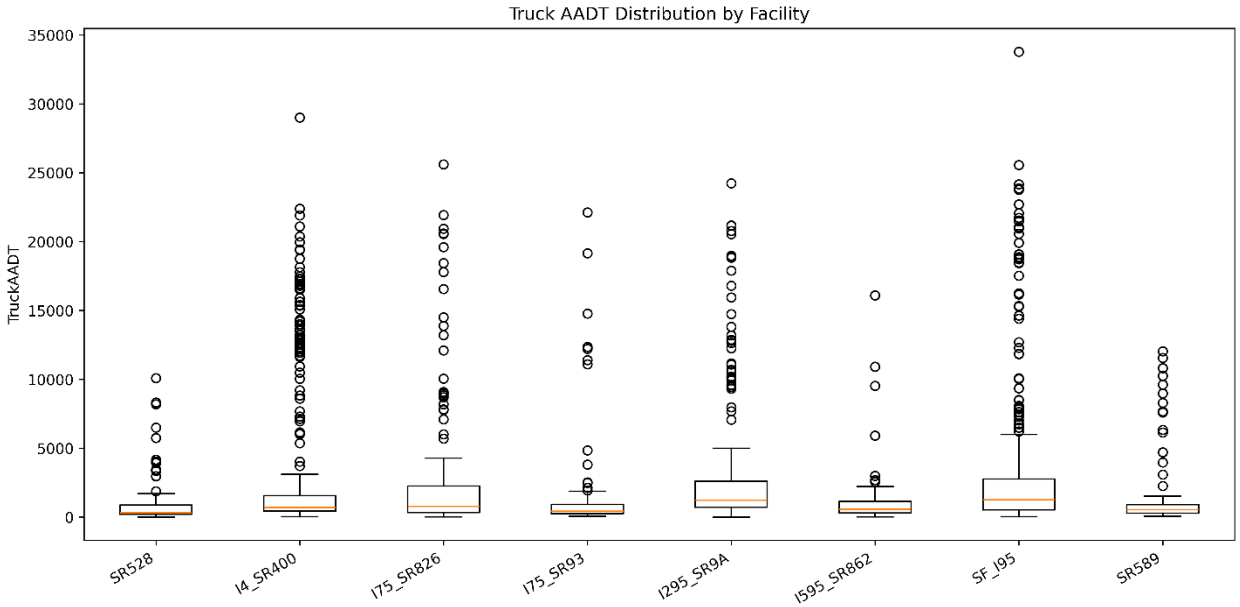


Figure 10. Truck AADT Distribution by Facility

Source: www.gis-fdot.opendata.arcgis.com

To provide additional insight into overall traffic conditions, the research team analyzed Annual Average Daily Traffic (AADT) data to evaluate general traffic volumes across the candidate facilities. The results, presented in **Figure 11**, reveal substantial variation in traffic demand among the evaluated corridors, reflecting differences in corridor function, urban context, and regional importance. Among all facilities, the South Florida segment of I-95 exhibits the highest overall traffic levels, with both mean and maximum AADT values confirming its role as the most heavily traveled freeway within the scope of this analysis. These results underscore I-95's function as a critical multimodal corridor accommodating intense commuter, freight, and intercity travel

demand. Following I-95, the I-75 / Palmetto Expressway (SR 826) and the I-4 corridor (SR 400 / I-4 Ultimate) also demonstrate very high traffic volumes, with elevated mean and maximum AADT values that suggest frequent congestion exposure and complex traffic dynamics, particularly in urbanized areas. Moderate-to-high AADT levels are observed along I-295 (SR 9A), I-75 (SR 93), and I-595 (SR 862), indicating corridors that support a mix of regional through traffic, freight circulation, and urban access movements.

In contrast, the Beachline Expressway (SR 528) and the Veterans Expressway (SR 589) exhibit comparatively lower overall traffic demand, with lower mean AADT values. These corridors primarily serve tourism-related and suburban commuter travel and therefore experience lower sustained traffic intensity and fewer extreme congestion conditions relative to the Interstate facilities. While they remain important at the regional level, their traffic profiles suggest a more limited role in statewide congestion and freight performance analysis.

Overall, the AADT results reinforce the hierarchical structure of Florida's freeway network. Corridors such as I-95, I-4, and the Palmetto Expressway carry the highest overall traffic loads and experience the most severe congestion pressures, while facilities such as I-295 and I-595 exhibit moderate but strategically important demand closely linked to major freight gateways and intermodal activity.

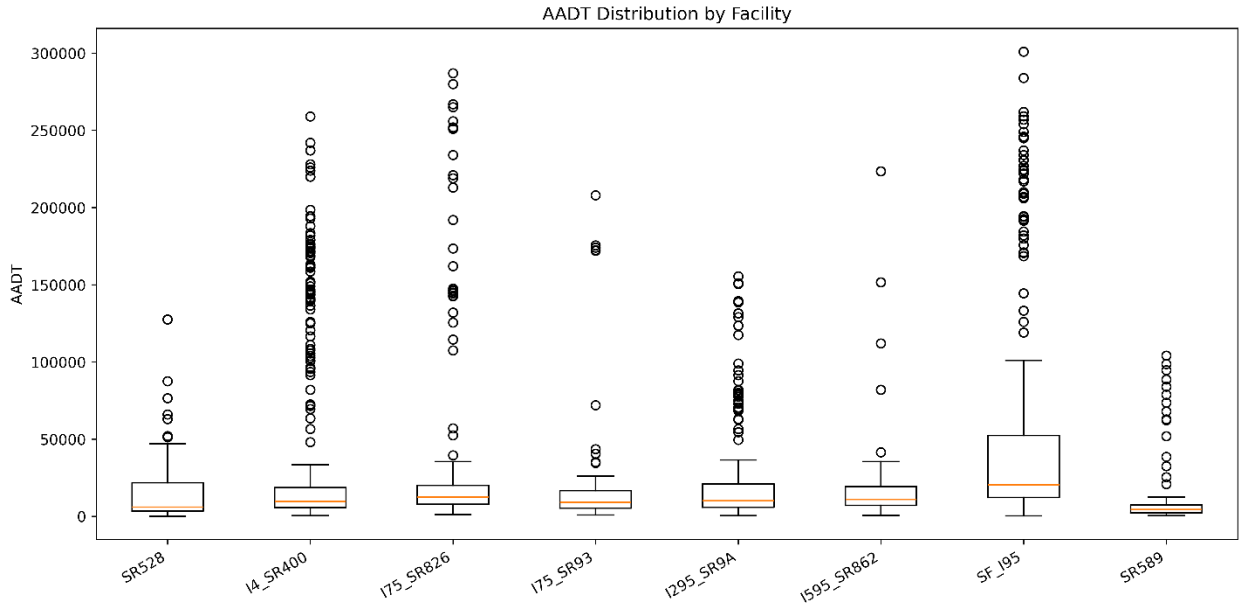


Figure 11. AADT Distribution by Facility

Source: www.gis-fdot.opendata.arcgis.com

Finally, to further assess the freight relevance of the evaluated facilities, the research team analyzed the share of trucks in total traffic, calculated as the ratio of TruckAADT to AADT. Results presented in **Figure 12** provide insight into the relative importance of freight traffic on each corridor, independent of absolute traffic volumes. The results reveal meaningful variation in truck

shares across facilities, reflecting differences in corridor function, access characteristics, and surrounding land use.

Among all facilities, I-295 (SR 9A) exhibits the highest average truck share, with the highest mean and maximum values observed. These findings indicate that a substantial portion of total traffic on I-295 consists of trucks, reinforcing its role as a freight-oriented beltway that supports port access, regional distribution, and intermodal connectivity in Northeast Florida. Despite moderate overall AADT levels, the elevated truck share highlights the corridor's disproportionate importance for freight mobility.

Relatively high average truck shares are also observed along the Veterans Expressway (SR 589). Although this facility carries lower absolute traffic volumes compared to major Interstate corridors, the elevated truck share suggests a notable presence of commercial vehicles, likely associated with regional distribution and suburban freight activity. In addition, the I-4 corridor (SR 400 / I-4 Ultimate) demonstrates a moderate-to-high truck share, reinforcing its importance for this analysis. The combination of meaningful truck shares, high absolute traffic volumes, and pronounced congestion dynamics underscores I-4's suitability for evaluating the impacts of Express Lane operations on freight reliability. Moderate truck shares are observed along the I-75 / Palmetto Expressway (SR 826) and I-75 (SR 93), reflecting significant freight activity within heavily urbanized and regional travel environments. The Beachline Expressway (SR 528) also displays a moderate average truck share, consistent with its role as an airport access and regional connector rather than a primary freight corridor.

In contrast, lower average truck shares are identified on South Florida I-95 and I-595 (SR 862). On I-95, the relatively lower share is attributable to extremely high overall traffic volumes dominated by commuter and intercity passenger travel, even though absolute truck volumes remain the highest among all evaluated corridors. Similarly, I-595 exhibits lower average truck shares consistent with its function as a short, urban connector serving a mix of commuter and drayage traffic.

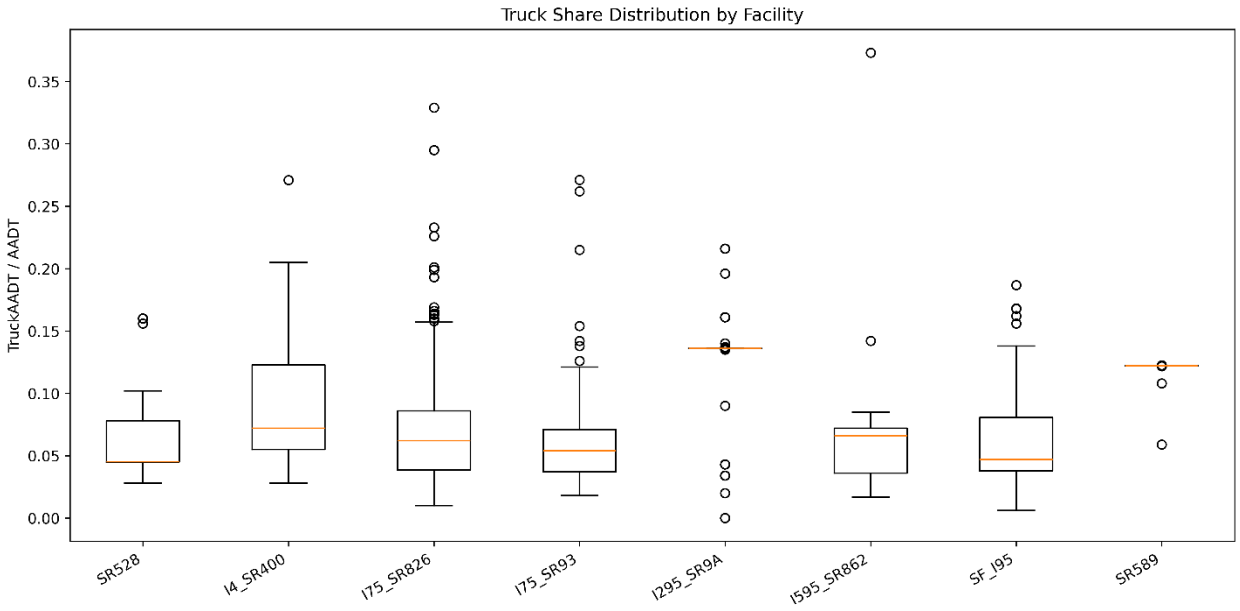


Figure 12. Truck Share Distribution by Facility

Source: www.gis-fdot.opendata.arcgis.com

Taken together, the AADT, TruckAADT, and truck share analyses provide a consistent and robust basis for identifying the Express Lane facilities of greatest interest for freight mobility evaluation. The South Florida segment of I-95 clearly emerges as the most critical corridor, combining the highest overall traffic volumes, the highest absolute truck volumes, and sustained systemwide freight usage. Although its truck share is comparatively lower, this is primarily attributable to extremely high passenger demand; in absolute terms, I-95 carries more trucks than any other evaluated facility, underscoring its role as Florida's primary long-haul and regional freight spine serving major ports, airports, and distribution centers. I-295 (SR 9A) also demonstrates strong freight relevance, characterized by moderate overall AADT, high TruckAADT, and the highest average truck share among all facilities, indicating a corridor where freight traffic constitutes a substantial proportion of total demand. This pattern reflects I-295's function as a freight-oriented beltway supporting port access, intermodal facilities, and regional distribution in Northeast Florida. Similarly, the I-4 corridor (SR 400 / I-4 Ultimate) attracts significant interest due to its combination of high overall traffic volumes, high absolute truck activity, and moderate-to-high truck shares, coupled with pronounced congestion and reliability challenges arising from intense freight–commuter interaction. In contrast, while facilities such as I-75, I-595, the Palmetto Expressway, and other toll expressways exhibit localized freight activity, they either lack Express Lane operations or display lower and less consistent freight indicators across all three metrics. Overall, the combined evidence from traffic volumes and truck composition clearly identifies I-95 Express, I-4 Ultimate, and I-295 Express East/West as the corridors with the greatest relevance for evaluating the impacts of Express Lanes on freight mobility.

2.1.2 Data Availability and Quality

The objective of this subtask is to assess the extent, quality, and temporal coverage of available data for the candidate Express Lane facilities, with particular emphasis on their suitability for before-and-after analysis. Beyond confirming data availability, it is essential to ensure that each facility offers a sufficiently long and clearly defined pre-implementation period, a stable post-implementation period, and reliable operational data throughout both phases. Such alignment is critical for isolating the impacts of Express Lane implementation on traffic and freight performance. Accordingly, each facility was examined individually with respect to its construction timeline, opening date, and operational maturity to determine whether an appropriate evaluation window can be established.

1. The I-295 Express East/West facilities present strong data coverage for before-and-after analysis. The West Beltway Express Lanes opened to traffic in May 2019, while the East Beltway Express Lanes were delivered in phases between Fall 2020 and 2021 and became fully operational in April 2022.
2. Similarly, I-595 Express benefits from mature and well-established data coverage. Construction began in June 2009, and the facility reached substantial completion in March 2014.
3. The I-75 Express facility also offers adequate data coverage for evaluation. Construction began in early 2014, and the Express Lanes opened to motorists in March 2018.
4. I-95 Express presents the most complex but also the richest data environment. The corridor was implemented through multiple phases over an extended period, beginning with Phase 1A and 1B between 2008 and 2010, followed by Phase 2 completed in 2016, and Phase 3 constructed between 2016 and 2023. While this phased delivery complicates the definition of a single implementation date, it also provides a unique opportunity to evaluate incremental impacts across successive stages of Express Lane expansion.
5. The I-75 / Palmetto Expressway corridor, although opened to traffic in March 2018 following construction that began in 2014.
6. The I-4 Ultimate project offers strong post-implementation data coverage, with construction beginning in February 2015 and the facility officially opening to traffic in February 2022.
7. The Beachline Expressway Express Lane segments were opened in stages, with the Florida's Turnpike–to–I-4 segment opening in July 2019 and the McCoy Road–to–Turnpike segment following in May 2020.
8. Finally, the Veterans Expressway conversion began in May 2013 and was fully opened to traffic in May 2018.

As discussed in Deliverable #1, the assessment of data availability across different analysis types identified several robust and complementary data sources. Traffic volumes and vehicle classification are well supported through platforms such as RITIS and JustFOIA, while safety analysis is strongly supported by Signal Four data, with the CMF Clearinghouse providing

additional resources for scenario-based evaluation. Emissions and fuel consumption impacts can be estimated using the MOVES model when supplemented with externally sourced speed and volume data. For freight-focused analyses, particularly strong datasets include FOX Weigh-in-Motion (WIM), NPMRDS truck-only data, JustFOIA vehicle classification data, and Florida Traffic Online (FTO) truck percentage information.

The availability of these datasets, all of which are publicly accessible, ensures a consistent level of data quality across facilities, regardless of geographic location. However, a key limitation arises with respect to before-and-after analysis requirements. In particular, RITIS data availability presents a temporal constraint, as the earliest consistently available data extend back only to 2014. Consequently, facilities selected for evaluation must not only have Express Lanes operational after 2014, but must also offer a sufficient pre-implementation period prior to opening in order to support robust and defensible before-and-after comparisons.

Based on this constraint and the central importance of RITIS data to the cause of this analysis, I-595 Express does not qualify for inclusion. Although traffic and operational data are available for this corridor, the Express Lanes became operational prior to 2014, limiting the availability of an adequate pre-implementation dataset. As a result, I-595 Express should excluded from further consideration, ensuring that the final set of study corridors is supported by consistent, high-quality data capable of enabling reliable before-and-after performance evaluation.

2.1.3 Variability in Traffic Patterns

As discussed previously, variability in traffic patterns is important for this analysis, as the selected datasets must be sufficiently detailed to capture temporal fluctuations in traffic and freight activity. Access to high-resolution data sources such as RITIS ensures that, regardless of facility or location, traffic volumes and speeds can be analyzed at fine temporal resolutions, including intervals as short as five minutes. Similarly, Signal Four Analytics provides safety-related data with hourly granularity, offering adequate resolution to support robust safety analyses. From a data-resolution perspective, therefore, the available datasets provide sufficient granularity to capture meaningful variability in traffic and safety conditions across all evaluated facilities.

From a facility perspective, however, not all corridors exhibit equally informative variability in traffic patterns. While there are not enough evidences to exclude facilities solely on the basis of perceived variability, differences in corridor function can influence the analytical insights that may be derived. Based on the AADT analysis presented earlier, the Beachline Expressway (SR 528) appears to exhibit relatively stable and predictable traffic patterns, largely driven by airport access and tourism-related commuters. Although seasonal fluctuations are present, variability on this corridor is primarily event- and season-driven rather than congestion- or reliability-driven. Similarly, the Veterans Expressway (SR 589) primarily serves suburban commuter travel, with comparatively low freight intensity and limited peak-period stress. Traffic conditions on this

facility tend to be consistent from day to day, with less pronounced congestion spikes and weaker interaction between freight and commuter traffic.

At this point, it is important to clarify, that these considerations should not be interpreted as substantial evidences for excluding such facilities from consideration. Rather, they provide contextual information that complements the overall corridor evaluation and helps distinguish facilities with high policy-relevant variability from those with more stable demand patterns. This distinction supports a more informed interpretation of results and reinforces the rationale for prioritizing corridors where variability is most closely linked to congestion dynamics and freight mobility outcomes.

2.1.4 Geographical Differences

This section discusses the geographical relevance of the examined facilities with respect to their proximity to freight-significant hubs and their role within Florida's freight transportation system. Geographic positioning is a critical parameter in evaluating freight impacts, as Express Lane facilities located near major ports, airports, intermodal terminals, and logistics clusters are more likely to influence freight mobility outcomes.

2.1.4.1 I-95 Express

I-95 Express, and I-95 more broadly, serves as Florida's primary north–south freight spine and a key segment of the national I-95 corridor. It supports long-haul freight, regional distribution, and port- and airport-related truck movements. In particular, the South Florida I-95 Express Lane segments provide direct access to major freight hubs, including PortMiami, Port Everglades, Miami International Airport, Fort Lauderdale–Hollywood International Airport, and multiple logistics and distribution clusters across Southeast Florida. This geographic concentration of freight generators makes I-95 Express highly significant from a freight mobility perspective.

2.1.4.2 I-4 Ultimate

I-4 Ultimate functions as the primary east–west connector between the Tampa Bay region and Central Florida's logistics, warehousing, tourism, and distribution centers. The corridor supports critical freight gateways such as Port Tampa Bay, Tampa International Airport, and Orlando International Airport. Its geographic position places it at the center of intense freight–commuter interaction, with pronounced peak-period congestion that directly affects freight reliability and travel times.

2.1.4.3 I-295 Express East/West

I-295 Express East/West plays a key role in supporting port-oriented and regional freight circulation in Northeast Florida. The corridor provides access to JAXPORT, Jacksonville International Airport, and major rail and highway intermodal facilities. Its beltway function facilitates freight movements between ports, distribution centers, and interstate corridors, reinforcing its geographic importance for freight activity in the Jacksonville region.

2.1.4.4 I-75 Express

I-75 Express supports significant long-haul and regional freight movement, particularly for north–south truck flows serving Southwest Florida, agricultural production areas, and interstate freight traffic. However, the Express Lane segments are more limited in spatial extent, and freight access is less directly connected to major seaports and airports when compared with I-95 and I-4. As a result, while geographically relevant for through freight, its influence on gateway-oriented freight activity is comparatively lower.

2.1.4.5 I-595 Express

I-595 Express has localized freight importance, particularly as an access corridor to Port Everglades and Fort Lauderdale–Hollywood International Airport. While this positioning makes it operationally relevant for drayage and short-haul freight movements, the corridor's short length and strong commuter orientation limit its representativeness for broader, systemwide freight mobility impacts.

2.1.4.6 I-75 / Palmetto Expressway

The I-75 / Palmetto Expressway corridor primarily serves dense urban commuter travel within Miami-Dade County. Although trucks are present, freight movement is not the dominant function of the facility. Traffic conditions are largely shaped by passenger demand, interchange density, and urban congestion rather than by freight-oriented travel patterns.

2.1.4.7 Beachline Expressway

The Beachline Expressway primarily supports airport access and tourism-related passenger travel between Orlando International Airport and the Space Coast. Freight volumes are relatively low, and the corridor does not function as a major freight backbone within the statewide network.

2.1.4.8 Veterans Expressway

The Veterans Expressway mainly serves suburban commuter traffic in the Tampa Bay region, with limited heavy truck activity and minimal direct access to major freight gateways. As such, its geographic relevance to freight movement is comparatively limited.

Although some facilities exhibit lower levels of freight activity, which could raise concerns regarding their relative significance for this analysis, another important consideration is geographic variability, which adds an additional layer of insight that is not bounded by a single regional context. By collectively capturing the major freight centers across Florida, I-95 Express, I-4 Ultimate, and I-295 Express East/West are uniquely positioned within the state's freight network. Each of these corridors directly serves multiple high-volume freight generators, including major seaports, international airports, intermodal terminals, and logistics clusters. I-95 Express functions as Florida's primary north–south freight spine, providing critical access to South Florida's ports and airports, while I-4 Ultimate anchors east–west freight connectivity between the Tampa Bay region and Central Florida's distribution and tourism economies. Similarly, I-295

Express East/West supports freight-oriented beltway circulation in Northeast Florida, linking JAXPORT and regional intermodal facilities to the Interstate system. Thus, the freight relevance of these corridors, combined with the variability inherent in their distinct geographic settings, introduces an analytically valuable dimension to the study and supports their selection as the strongest candidates for prioritization in the subsequent phases of analysis.

2.1.5 Policy and Regulatory Constraints

Policy and regulatory frameworks play a critical role in shaping how Express Lane facilities operate and, consequently, how they can be used by freight vehicles. These constraints influence vehicle eligibility, tolling mechanisms, enforcement practices, and operational flexibility, all of which affect the extent to which Express Lanes can improve freight mobility. The following discussion summarizes the key policy and regulatory characteristics of the evaluated facilities and highlights their implications for freight-focused analysis.

2.1.5.1 I-295 Express East/West

The I-295 Express Lanes in Jacksonville operate under a time-of-day tolling structure and require the use of a SunPass or another interoperable transponder. Toll-by-plate is not permitted, and vehicles using the lanes during toll hours without a transponder are subject to a $25 violation fee in addition to the toll. During peak periods (Monday–Friday, 6:00–10:00 a.m. and 3:00–7:00 p.m.), a static toll of $0.50 is charged, while the lanes are toll-free during off-peak hours. From a policy perspective, the transponder-only requirement may influence freight participation, particularly among smaller carriers, while the toll-free off-peak operation creates opportunities to examine freight behavior under different pricing regimes.

2.1.5.2 I-595 Express

I-595 Express consists of three reversible, tolled Express Lanes with strict vehicle eligibility requirements. Only two-axle vehicles are permitted, and all users must possess a SunPass transponder with a prepaid account; neither cash payments nor toll-by-plate options are available. As a result, trucks with three or more axles are excluded from the facility. This regulatory constraint significantly limits the applicability of I-595 Express for freight analysis, as it restricts access for the majority of heavy commercial vehicles and confines freight use primarily to light-duty or service vehicles.

2.1.5.3 I-75 Express

The I-75 Express facility operates as a four-lane tolled roadway located within the median of I-75, featuring two Express Lanes in each direction separated from general-use lanes by buffer zones and concrete barriers. While the geometric design supports managed-lane operations, policy constraints and limited Express Lane continuity reduce its direct relevance to freight gateways. The facility's regulatory framework primarily focuses on traffic separation and capacity management rather than explicit freight accommodation, which may limit its analytical value for freight-specific performance evaluation.

2.1.5.4 I-95 Express

The I-95 Express Lanes originated as converted high-occupancy vehicle (HOV) lanes and now operate as dynamically priced managed lanes. Single-occupancy vehicles are permitted to use the lanes by paying a toll, which is dynamically adjusted to maintain minimum operating speeds of approximately 45 mph. This performance-based pricing framework directly supports travel time reliability, making I-95 Express particularly relevant for freight analysis. Importantly, the policy structure allows eligible trucks to use the lanes, subject to tolling and axle requirements, enabling the evaluation of freight responses to congestion pricing and reliability incentives.

2.1.5.5 I-4 Ultimate

I-4 Ultimate initially operated under a flat, per-segment tolling scheme during its introductory phase. Beginning February 24, 2025, FDOT transitioned the facility to a dynamic tolling structure, aligning its operational policy with other managed-lane systems in the state. This regulatory evolution provides a unique opportunity to examine freight behavior under different tolling regimes within the same corridor. The absence of axle-based exclusions further enhances I-4 Ultimate's suitability for freight-focused analysis.

2.1.5.6 Beachline Expressway

On the Beachline Expressway (SR 528), Express Lanes are governed by restrictive vehicle eligibility rules. Only two-axle vehicles are permitted, and trucks with three or more axles are prohibited. Users must carry a SunPass or interoperable transponder, and tolling follows the general toll structure applied to all lanes on the facility. While transit buses, school buses, and vanpools are allowed, the exclusion of heavier trucks significantly limits the corridor's relevance for freight mobility analysis.

2.1.5.7 Veterans Expressway

The Veterans Expressway operates as a toll expressway rather than a managed Express Lane facility. Similar to SR 528, only two-axle vehicles are permitted, with three-or-more-axle trucks excluded. Tolling is uniform across lanes, and access requires a SunPass or interoperable transponder. These regulatory constraints, combined with the absence of dynamic pricing or freight-oriented policies, reduce the corridor's applicability for evaluating Express Lane impacts on freight movement.

Overall, the policy and regulatory assessment indicates that facilities differ substantially in terms of freight eligibility and operational flexibility. Corridors such as I-95 Express, I-4 Ultimate, and I-295 Express East/West offer regulatory environments that allow meaningful freight participation and support performance-based evaluation. In contrast, facilities with restrictive axle-based eligibility rules or toll-expressway operations, such as I-595 Express, the Beachline Expressway, and the Veterans Expressway, present potential limitations for freight-focused analysis. These distinctions further reinforce the prioritization of I-95, I-4, and I-295 as the most suitable study corridors for assessing the impacts of Express Lanes on freight mobility.

2.1.6 Stakeholder Engagement

Stakeholder engagement is a critical element in the successful evaluation of Express Lane impacts, as meaningful insights and access to high-quality data often depend on coordination with transportation agencies, freight operators, and local governments. For the facilities under consideration, existing institutional frameworks and active stakeholder ecosystems provide a strong foundation for effective engagement and data sharing. However, stakeholder

The stronger candidate facilities, particularly I-95 Express, I-4 Ultimate, and I-295 Express East/West, are all located within regions that involve multiple engaged stakeholders with established roles in freight planning and operations. At the agency level, coordination with Florida Department of Transportation Districts responsible for these corridors facilitates access to traffic operations data, Express Lane performance metrics, and planning documentation. These facilities are also closely tied to major freight gateways, enabling direct engagement with port authorities such as PortMiami, Port Everglades, and JAXPORT, as well as airport authorities and regional logistics hubs. These stakeholders can provide operational perspectives on truck routing, access constraints, peak-period freight activity, and the role of Express Lanes in supporting time-sensitive movements. In addition, these corridors traverse metropolitan regions with active freight advisory committees, metropolitan planning organizations (MPOs), and local governments that routinely engage with trucking firms, distribution centers, and logistics service providers. Such institutional structures support outreach to freight carriers and shippers who operate regularly on these facilities and can offer qualitative insights into Express Lane usage, perceived reliability benefits, toll sensitivity, and operational constraints.

However, in the context of this project, stakeholder engagement is also meaningful when it involves entities that are either affected by Express Lane performance or in a position to use the findings to inform decisions. For freight-focused Express Lane analysis, this includes transportation agencies responsible for operations and policy, freight carriers and logistics providers whose costs and reliability are directly influenced by congestion and tolling, and local or regional governments that plan infrastructure investments and land use around freight corridors. Thus, in that context, corridors such as I-95 Express, I-4 Ultimate, and I-295 Express East/West are particularly well suited for stakeholder engagement. These facilities serve major freight generators and are actively used by trucking firms, port operators, airport authorities, and regional planners who have a vested interest in understanding how Express Lanes affect freight efficiency and reliability. In contrast, facilities with limited freight activity or primarily commuter- or tourism-oriented demand might attract fewer freight associated stakeholders who would directly benefit from the study's outcomes.

2.1.7 Recommended Priority Express Lane Corridors for Freight Analysis

Based on the aforementioned evaluation provided in this section, the research team recommends prioritizing:

1. I-95 Express,
2. I-4 Ultimate,
3. I-295 Express East/West

These facilities consistently rank highest across multiple quantitative and qualitative criteria. From a traffic perspective, they exhibit the strongest freight signals, combining high overall traffic volumes (AADT), high absolute truck volumes (TruckAADT), and, in the case of I-295, the highest truck share among all evaluated corridors, indicating a disproportionate reliance on freight movements. Geographically, these corridors are uniquely positioned to serve Florida's most critical freight hubs: I-95 Express functions as the state's primary north–south freight spine with direct access to major seaports, international airports, and logistics clusters in South Florida; I-4 Ultimate anchors east–west connectivity between the Tampa Bay region and Central Florida, linking ports, airports, and large-scale distribution centers under intense freight–commuter interaction; and I-295 Express East/West supports freight-oriented beltway circulation in Northeast Florida, providing essential access to JAXPORT, intermodal rail facilities, and regional distribution networks. In addition, these corridors span Florida's four major metropolitan hubs, Miami, Tampa, Orlando, and Jacksonville, providing insights that are not constrained to a single region but are representative of freight mobility conditions across the entire state. In addition, all three corridors exhibit pronounced temporal and spatial variability in traffic and truck movements, making them well suited for evaluating reliability, congestion, and performance impacts. Finally, from a stakeholder perspective, this prioritization is of high importance, as it directly involves transportation agencies, port authorities, freight carriers, and local governments with a strong interest in the study outcomes.

2.2 Data Collection and Analysis

This section describes the data collected for multiple performance metrics in order to support the before-and-after analysis conducted in later stages of the study. Specifically, the datasets include traffic volumes, travel times, travel speeds, safety data, and other relevant performance measures necessary to evaluate operational conditions on the selected corridors.

2.2.1 Traffic Volume Data

2.2.1.1 Truck Volumes

This section provides metrics including the TruckAADT distributions for I-4 (SR-400), I-95, and I-295 (SR-9A) over the 2020–2024 period highlight distinct yet complementary freight activity patterns across Florida's priority corridors. More specifically, results presented in **Figure 14**, highlight that the I-95 consistently exhibits the highest overall freight intensity, characterized by stable median TruckAADT values coupled with an exceptionally wide upper tail and numerous high-end outliers. This pattern verifies I-95's role as Florida's primary long-haul and gateway freight spine, where freight demand is structurally high and spatially concentrated near major ports, airports, and logistics hubs. In contrast, results presented in **Figure 13**, demonstrate that I-4 exhibits a more gradual upward shift in median TruckAADT over time, along with a widening

interquartile range in later years, indicating steady growth in freight activity and increasing spatial variability driven by freight–commuter interaction within the Central Florida region. In addition, the presence of high upper-end values in recent years further suggests emerging freight-intensive segments along the corridor. Also, results presented in **Figure 15**, highlight that I-295 displays the most pronounced relative growth, with rising medians, rapidly expanding interquartile ranges, and increasing upper extremes through 2024, signaling a beltway corridor where freight demand is both growing and becoming more unevenly distributed across segments.

Altogether, these results demonstrate that while I-95 carries the highest absolute truck volumes, I-4 and I-295 exhibit dynamic growth and variability patterns that are particularly informative for analyzing congestion, reliability, and Express Lane performance impacts on freight mobility.

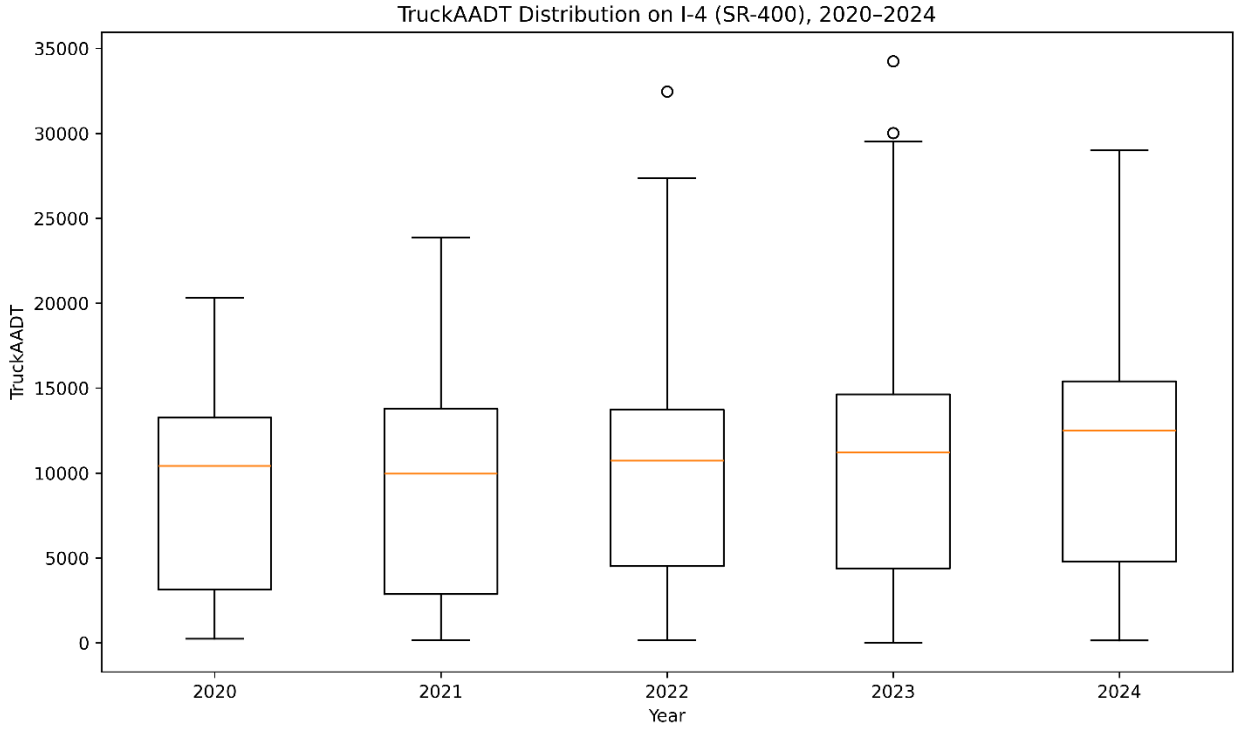


Figure 13. Truck AADT - I-4 (SR-400)

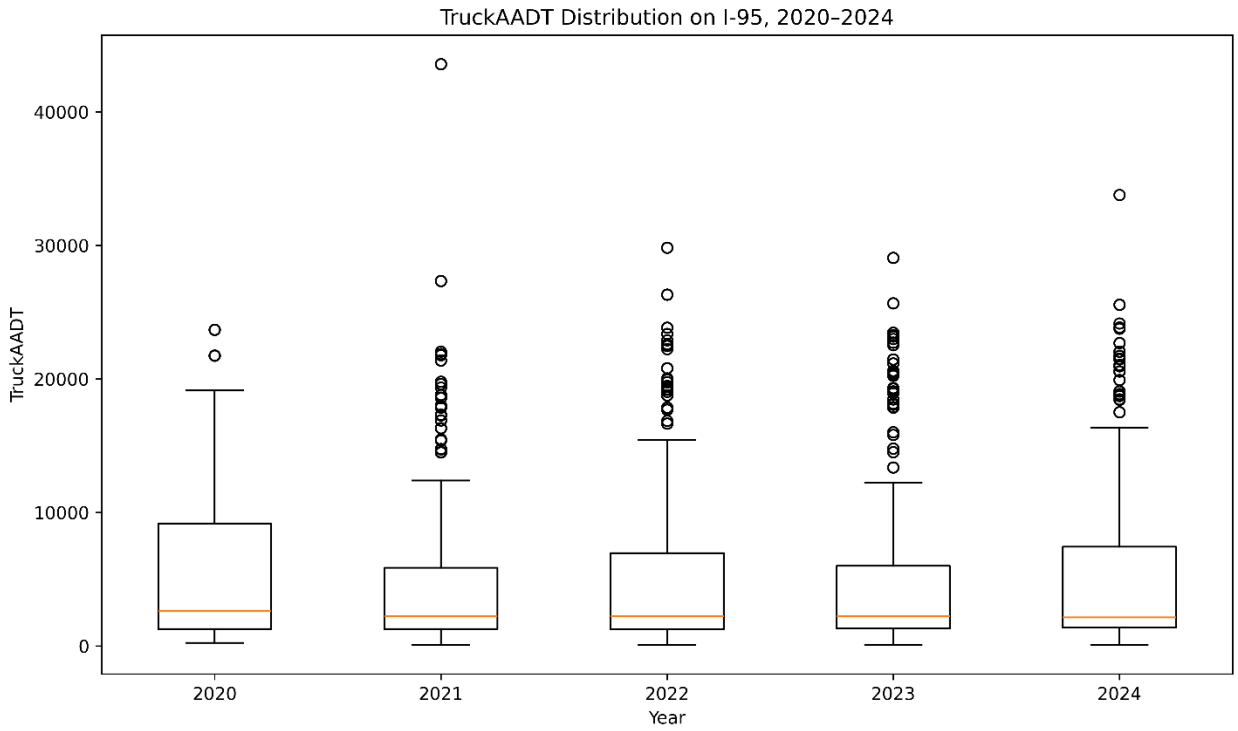


Figure 14. Truck AADT - I-95

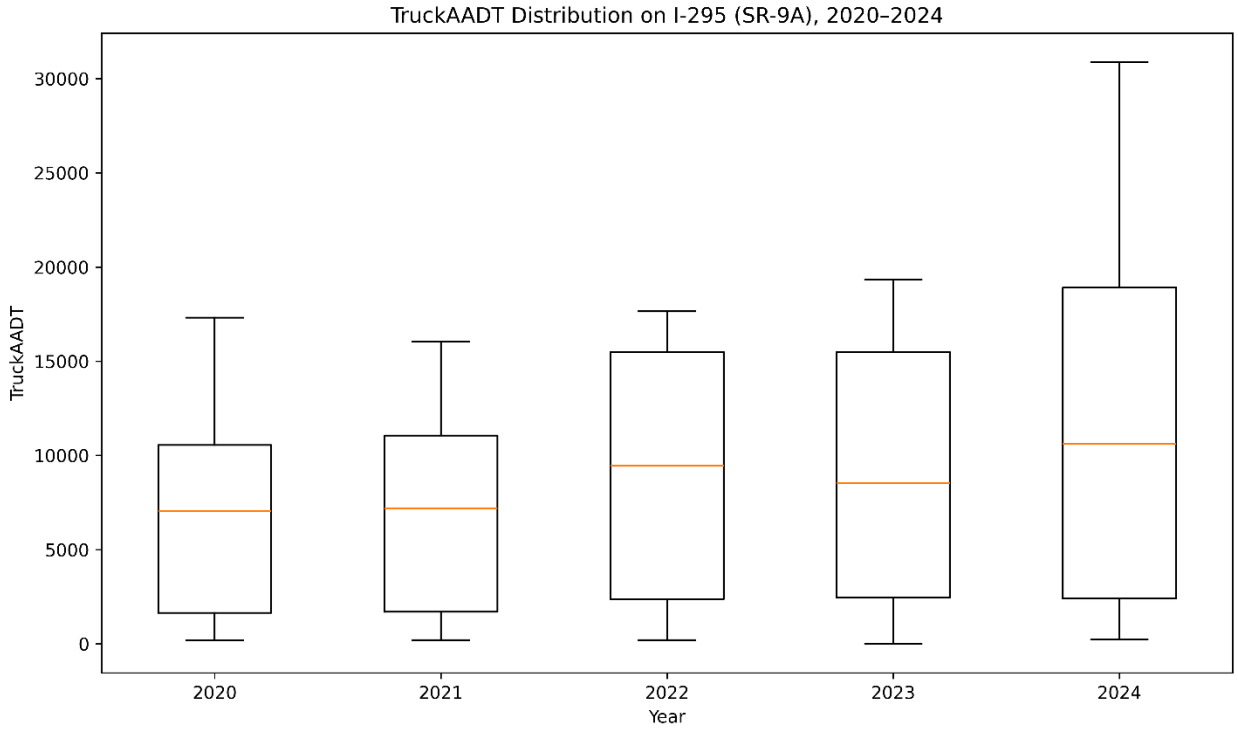


Figure 15. Truck AADT - I-295(SR-9A)

2.2.1.2 Commercial Vehicles Traffic Volumes

iv. I-4

To further enhance the level of detail in the analysis, a comparison is conducted between the General Purpose Lanes (GPL) and the Express Lanes (EL) using average hourly traffic volumes across both peak and off-peak seasons. For Florida, the peak season is defined as February through April, while the off-peak season corresponds to June through August. The results, presented in **Figure 16** and **Figure 17**, indicate that there are no substantial differences in the overall diurnal traffic volume patterns between peak and off-peak seasons. In both cases, I-4 exhibits extended periods of high demand rather than short, sharply defined peak spikes. This persistent congestion pattern is particularly relevant for freight movement, as this can potentially expose trucks operating during daytime and peak periods to prolonged congestion and reliability challenges.

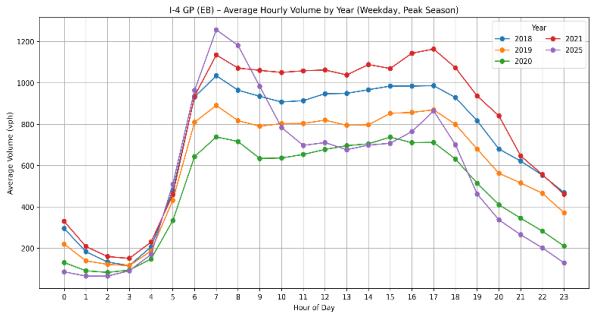


Figure 16. I-4 GPL (EB) - Average Hourly Volume by Year (Peak Season)

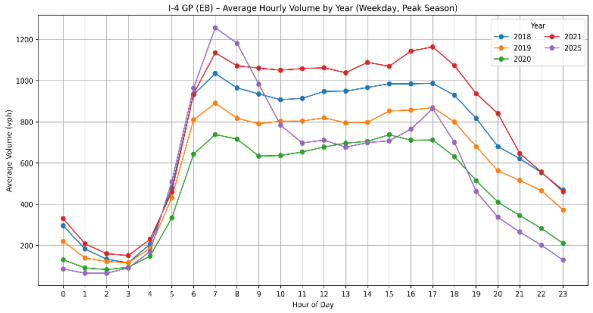


Figure 17. I-4 GPL (EB) - Average Hourly Volume by Year (Non-Peak Season)

Additionally, the same performance metrics for the EL facilities indicate that seasonal variation does not materially alter hourly volume patterns. Instead, the results presented in **Figure 18** and **Figure 19** demonstrate that Express Lane usage on I-4 is strongly time-of-day dependent and highly responsive to congestion conditions in the general-purpose lanes. This behavior reinforces the potential value of Express Lanes in improving travel time reliability rather than simply accommodating seasonal demand fluctuations. From a freight mobility perspective, these patterns suggest that Express Lanes can provide meaningful benefits during extended peak periods, particularly in the afternoon, when congestion exposure is highest and the risk of delivery delays is greatest.

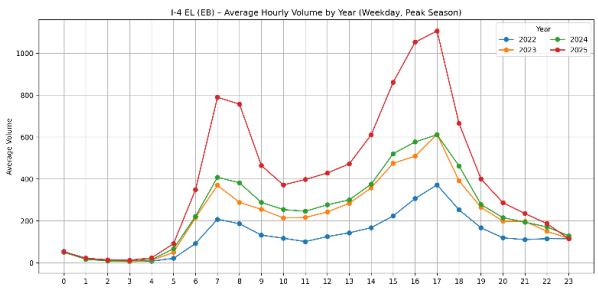


Figure 18. I-4 EL (EB) - Average Hourly Volume by Year (Peak Season)

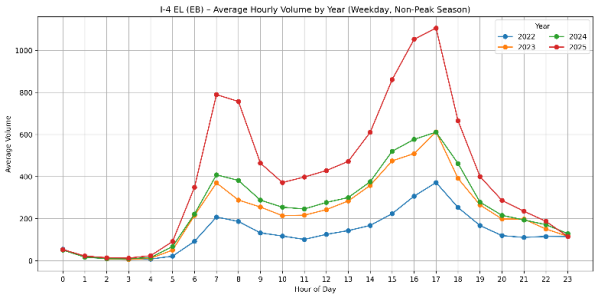


Figure 19. I-4 EL (EB) - Average Hourly Volume by Year (Non-Peak Season)

v. I-95

Results presented in **Figure 20** and **Figure 21** indicate that interannual differences in traffic volume levels are relatively modest, reflecting stable weekday demand during the non-peak season. The persistence of similar hourly profiles across multiple years suggests that the temporal structure of traffic demand on I-95 is robust and not strongly influenced by seasonal effects, and therefore seasonality does not yield additional insights for this corridor. One notable exception is the outlier observed in Figure 16 for the year 2018, which is attributable to detector data availability and coverage limitations during that specific year and non-peak season months, rather than a true increase in traffic demand. Despite this isolated anomaly, the figures effectively capture consistent traffic patterns and confirm that I-95 experiences long-duration peak congestion with sustained high volumes throughout the day, reinforcing its relevance for reliability- and performance-oriented analyses**.**

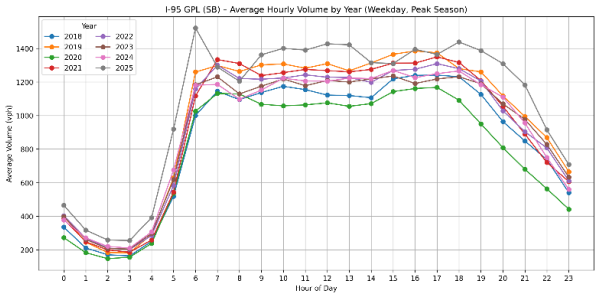


Figure 20. I95 GPL (SB) - Average Hourly Volume by Year (Peak Season)

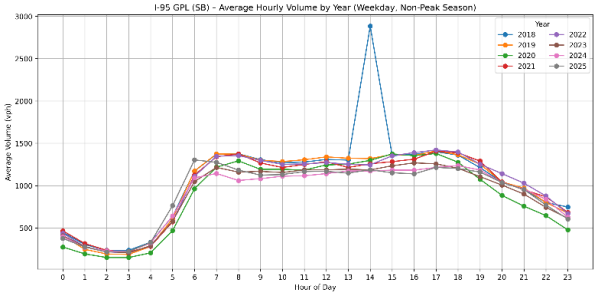


Figure 21. I95 GPL (SB) - Average Hourly Volume by Year (Non-Peak Season)

Results presented in **Figure 22** and **Figure 23** indicate that interannual variation in Express Lane usage is evident but systematic. Earlier years (e.g., 2020) exhibit lower overall Express Lane volumes, while later years, particularly 2023 through 2025, show consistently higher usage across peak periods. This upward trend reflects increasing user familiarity with the facility, worsening congestion in the general-purpose lanes, and a growing willingness to pay for travel time reliability. Despite differences in absolute volume levels, the hourly usage profiles remain stable across years, indicating a robust behavioral response to congestion rather than seasonal or random fluctuations. Consistent with earlier findings, seasonality does not yield additional insights into Express Lane

performance. From a freight mobility perspective, the sustained Express Lane demand during midday and afternoon periods is especially important, as these time windows coincide with active freight delivery and drayage operations, suggesting that I-95 Express Lanes can provide meaningful reliability benefits for time-sensitive truck movements during the most congested portions of the day.

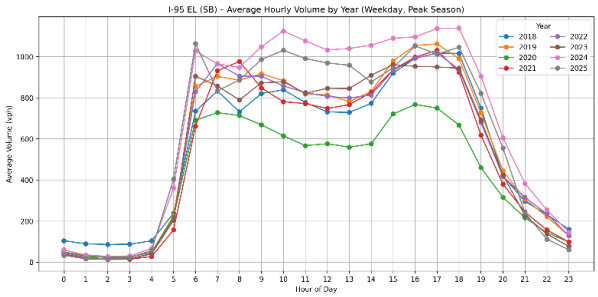


Figure 22. I95 EL (SB) - Average Hourly Volume by Year (Peak Season)

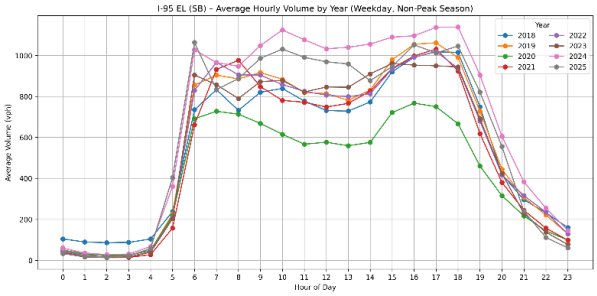


Figure 23. I95 EL (SB) - Average Hourly Volume by Year (Non-Peak Season)

vi. I-295

Results presented in **Figure 24** and **Figure 25** indicate that interannual variation in traffic volumes on I-295 is evident but systematic. More specifically, the year 2020 exhibits consistently lower volumes across all hours, reflecting potential pandemic-related reductions in travel demand. In contrast, later years, show higher and more stable peak-period volumes. Despite these differences in magnitude, the overall hourly traffic profiles remain remarkably consistent across years, suggesting that the temporal structure of demand on I-295 is stable and largely insensitive to seasonal variation; once again, seasonality does not yield additional insights. From a freight mobility perspective, the persistence of high volumes during both morning and afternoon periods is particularly relevant, as these time windows coincide with active freight circulation associated with port access and intermodal transfers, which are especially prominent in the Jacksonville area.

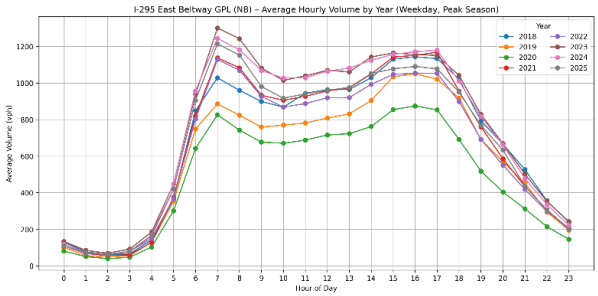


Figure 24. I295 GPL (NB) - Average Hourly Volume by Year (Peak Season)

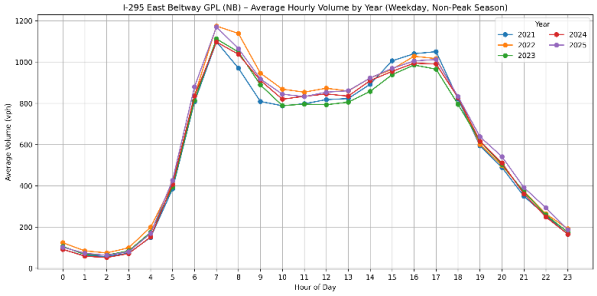


Figure 25. I295 GPL (NB) - Average Hourly Volume by Year (Non-Peak Season)

It is important to note that results presented in **Figure 26** and ***Figure 27*** reflect only one year of Express Lane data (2025) due to data availability constraints for the I-295 East Beltway Express

Lanes. As such, interannual comparisons cannot be made for this facility at this stage. Nevertheless, the observed diurnal profile aligns closely with Express Lane usage patterns observed on other corridors, indicating that Express Lane demand on I-295 is highly time-of-day dependent and congestion-responsive

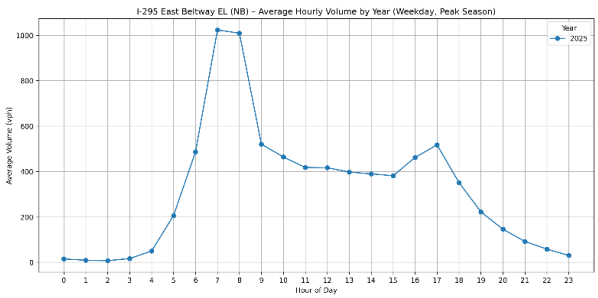


Figure 26. I295 EL (NB) - Average Hourly Volume by Year (Peak Season)

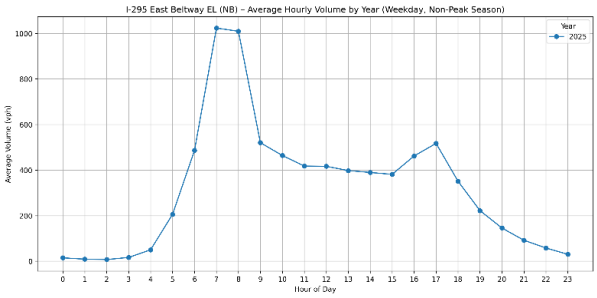


Figure 27. I295 EL (NB) - Average Hourly Volume by Year (Non-Peak Season)

2.2.2 Travel Time Data

This section evaluates travel time reliability using buffer index (minutes) and planning time (minutes), two metrics that capture the additional time travelers must allow to ensure on-time arrival under variable traffic conditions. These measures are particularly relevant for freight mobility, as they reflect schedule risk and delay uncertainty rather than average conditions alone. However, due to the absence of more detailed, facility-specific trajectory data across all study corridors, the reliability results presented in this section were generated directly using RITIS.org, which provides consistent, corridor-level travel time analytics suitable for comparative and before-and-after evaluation

2.2.2.1 Buffer Index (BI) and Planning Time Index (PTI) Analytics

1. I-4

Results presented in **Figure 28** and **Figure 29** indicate that unreliability on I-4 is strongly time-of-day dependent, with relatively stable and lower variability during overnight and late-morning periods, followed by a pronounced deterioration during the late afternoon peak. While buffer times generally remain modest for most of the day, a sharp spike is observed around 4:00–5:00 p.m., signaling heightened variability and an increased need for additional travel time to ensure on-time arrival. This pattern is further reinforced by the Planning Time Index, which shows elevated planning times throughout the day and a substantial increase during the afternoon peak, when required planning times exceed typical off-peak levels by a wide margin. The concurrence of these spikes across both reliability measures confirms that the afternoon peak represents the most critical reliability bottleneck on I-4. From a freight mobility perspective, this finding is particularly important, as these periods coincide with active freight delivery and distribution operations, potentially exposing trucks to increased delay risk and scheduling uncertainty.

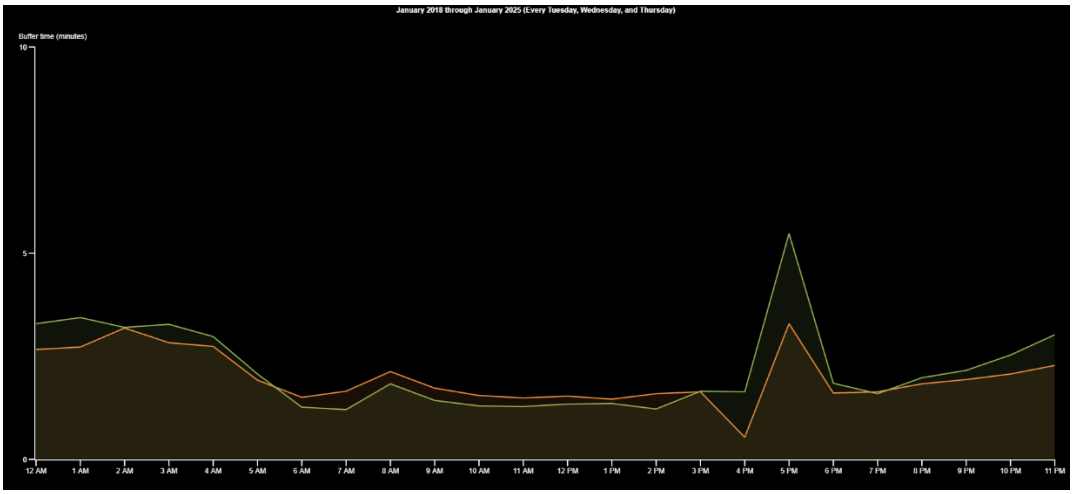


Figure 28. Buffer Index (min) - I-4

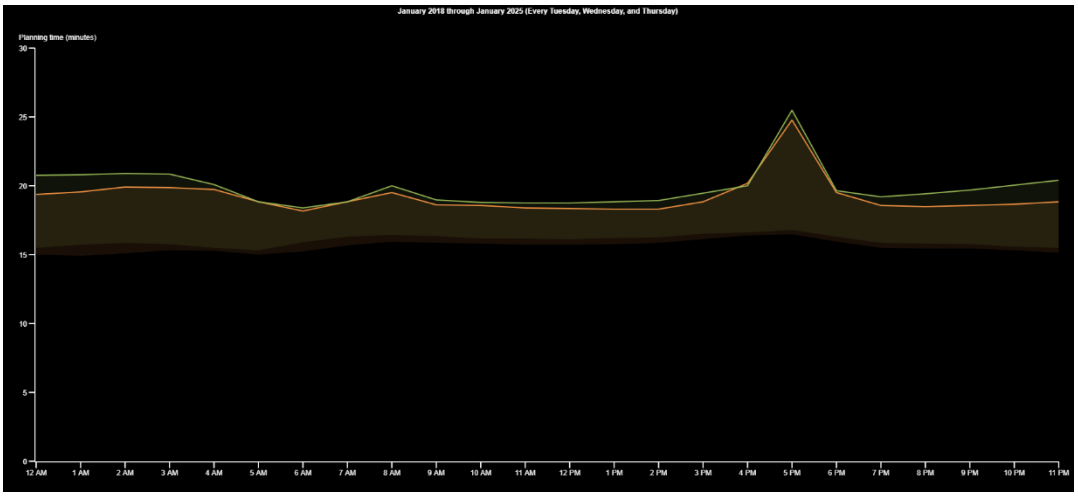


Figure 29. Planning Time (min) – I-4

vii. I-95

Results presented in **Figure 30** and **Figure 31** indicate that this specific South Florida segment of I-95 experiences severe and persistent travel time unreliability, with pronounced peaks during both the morning and afternoon periods. The Buffer Time Index reveals sharp increases in required buffer time beginning around 6:00 a.m., peaking during the morning commute, and rising even more dramatically during the afternoon peak between approximately 4:00 and 5:00 p.m., when variability reaches its highest levels. These findings are reinforced by the Planning Time results, which show that travelers must allow substantial additional time throughout the day, with required planning times remaining elevated even during off-peak hours and exceeding 90 minutes in the morning peak and 120 minutes during the afternoon peak. The concurrence of extreme peaks across both reliability measures confirms that unreliability on I-95 is not confined to short congestion events but reflects sustained structural congestion and high incident sensitivity. From a freight mobility perspective, these conditions are particularly critical, as the periods of greatest

unreliability, can potentially coincide with active drayage, regional distribution, and port- and airport-related truck movements in South Florida.

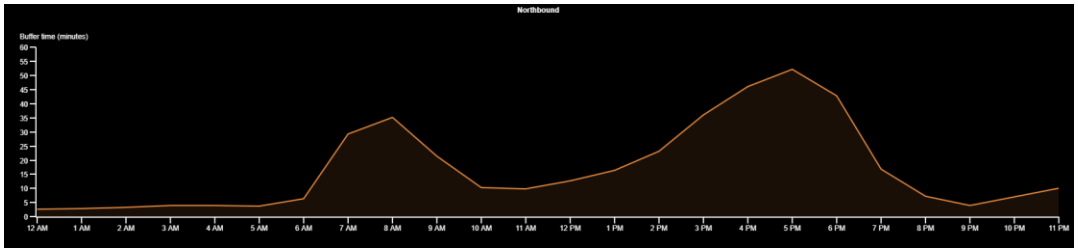


Figure 30. Buffer Index (min) – I95

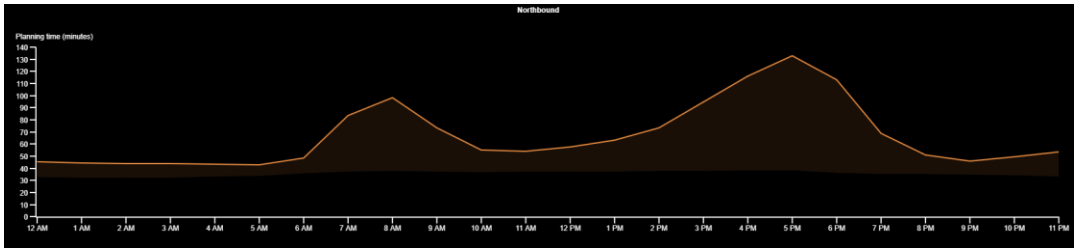


Figure 31. Planning Time (min) – I-95

viii. I-295

Results presented in **Figure 32** and **Figure 33** demonstrate low buffer times and low planning times during overnight, morning, and early afternoon hours, reflecting stable and predictable operating conditions consistent with I-295's beltway function. However, beginning in the mid-afternoon, reliability deteriorates rapidly, with the Buffer Index increasing sharply and the Planning Time Index peaking between approximately 4:00 and 5:00 p.m. This concurrence across both measures confirms that the late afternoon period represents a localized reliability bottleneck, rather than a corridor-wide or all-day issue.

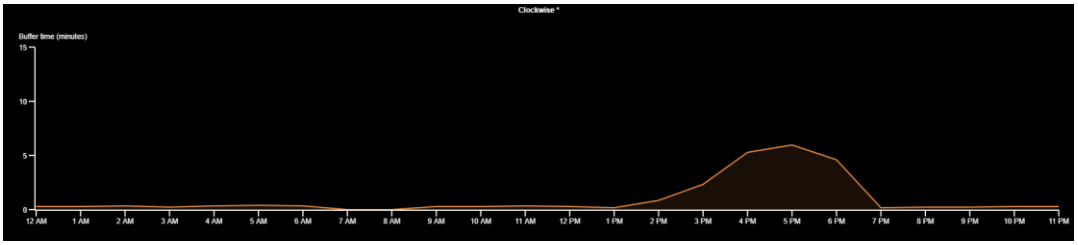


Figure 32. Buffer Index (min) – I295

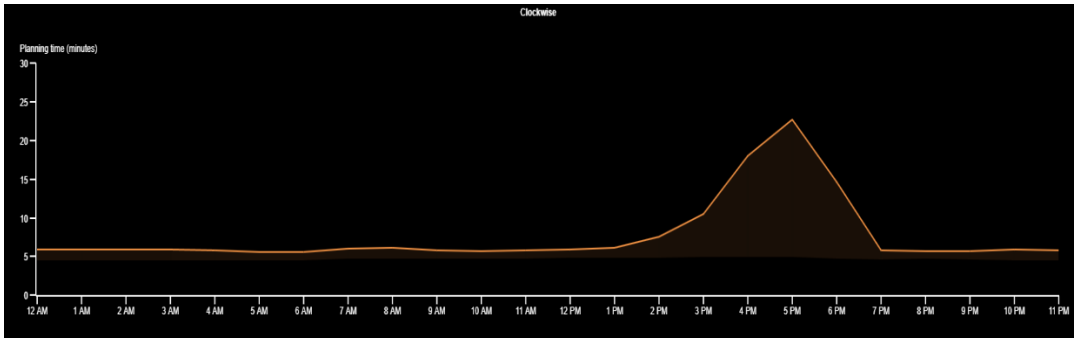


Figure 33. Planning Time (min) – I-295

2.2.3 Travel Speeds Data

The research team was able to obtain the necessary travel speed data to support the before-and-after analysis outlined in the scope of work. Specifically, travel speed data were collected from RITIS.org and processed to support a detailed assessment of operating conditions on both general-purpose lanes and Express Lanes, before and after the implementation of Express Lane facilities. The processed data were analyzed and visualized through a series of figures designed to provide insights into changes in traffic performance attributable to Express Lane operations.

As requested, the analysis focuses on typical weekdays (Tuesday through Thursday) and distinguishes between peak and non-peak travel seasons. Travel speeds were summarized by time period, including the AM peak (7:00 a.m. – 9:00 a.m.), off-peak period (9:00 a.m. – 4:00 p.m.), and PM peak (4:00 p.m. – 6:00 p.m.), as well as for the average 24-hour day. This approach ensures consistency across facilities and provides a robust basis for comparing operational performance before and after Express Lane implementation

2.2.4 Safety Data

As requested, the research team obtained crash data from FDOT's SIGNAL4 Analytics for the selected corridors to support a before-and-after safety evaluation associated with the implementation of Express Lanes. Available data include crash frequency, crash type, severity levels (property damage only, injury, and fatal crashes), and reported contributing factors. These data were reviewed to assess potential safety impacts attributable to Express Lane operations.

However, while these descriptive crash metrics provide useful contextual information, they do not consistently yield actionable insights suitable for a robust before-and-after evaluation at the corridor level, particularly given variability in exposure, reporting practices, and limited post-implementation observation periods for some facilities. As a result, the research team will continue to monitor and qualitatively assess crash characteristics, but for the purposes of this report, the primary safety comparison will rely on normalized hourly crash counts when evaluating conditions before and after Express Lane implementation. This approach provides a more consistent and interpretable basis for comparative safety assessment across corridors and time periods.

2.2.5 Values of Travel Time Data

The Value of Travel Time (VTT) is a key economic metric used in transportation planning and benefit-cost analysis to monetize the benefits of reduced travel time and improved reliability. It represents the amount users , including both personal travelers and freight carriers, are willing to pay to save time, thereby translating time savings into economic terms for performance evaluation and investment decisions. The U.S. Department of Transportation (2016), emphasizes that the value of travel time is a critical factor in assessing infrastructure investments and rulemaking initiatives, as reductions in delay for passenger and freight travel are fundamental objectives of transportation improvements. Also, many freight carriers and shippers often place an even higher value on travel time and reliability than passenger vehicles, as timely deliveries are essential to competitiveness and supply-chain performance. Therefore, VTT provides a valuable framework for assessing the economic benefits of Express Lane operations by converting travel time and reliability improvements, captured through various metrics, into dollar values that support decision-making and comparative evaluation.

However, for the purposes of this report, our research team was not able to develop a fully defensible Value of Travel Time (VTT) calculation, as such an analysis would require the adoption of several assumptions related to user behavior, cost structures, and reliability valuation. Given these limitations, VTT estimation is not included at this stage. The research team will continue to refine this component and will provide an updated VTT-based assessment in a subsequent phase of the study as additional assumptions and supporting information are finalized.

2.3 Conduct Before and After Analysis

This section presents the before-and-after analysis conducted to evaluate changes in corridor performance associated with the implementation of Express Lanes. Using the datasets described in the previous section, the analysis compares operational conditions on the selected corridors during periods preceding and following Express Lane deployment. The objective is to assess how Express Lanes influence traffic operations, reliability, and safety, with a particular focus on impacts to General-Purpose Lanes and freight-related performance under real-world conditions.

2.3.1 Average Travel Times

2.3.1.1 I-4

Results presented in **Figure 36** demonstrate the average weekday travel time profiles on the I-4 General Purpose Lanes (GPL), shown by hour of day. These results reveal distinct before-and-after patterns associated with the implementation of the Express Lanes. In the pre-implementation period (2014–2021), travel times exhibit pronounced morning (around 7–9 AM) and afternoon (approximately 3–6 PM) peaks, with the PM peak consistently producing the highest delays. These peaks indicate recurring congestion and limited capacity to absorb demand during commuter-heavy periods.

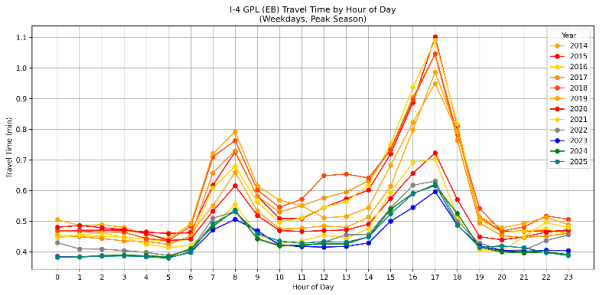


Figure 34. I4 GPL (EB) - Average Hourly Travel Time by Year (Peak Season)

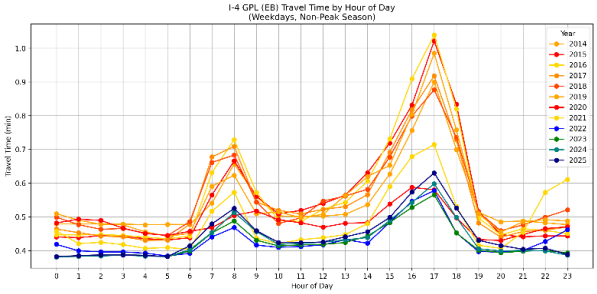


Figure 35. I4 GPL (EB) - Average Hourly Travel Time by Year (Non-Peak Season)

In the post-implementation period (2023–2025), average GPL travel times during peak hours are noticeably lower and more stable compared to earlier years, particularly during the PM peak. While congestion remains present, the magnitude of peak-period travel times is reduced, and the hourly profiles appear smoother, suggesting improved traffic distribution and reduced spillback effects. This pattern is consistent with Express Lanes absorbing a portion of peak demand, thereby relieving pressure on the general-purpose lanes. Overall, the results indicate that the introduction of Express Lanes on I-4 has contributed to measurable improvements in peak-period GPL performance, especially during the most congested afternoon hours, while off-peak travel times remain largely unchanged. However, as illustrated in **Figure 34** and **Figure 35**, seasonality does not appear to affect travel times in a statistically significant manner. The observed hourly travel time profiles remain largely consistent between peak and non-peak seasons, indicating that congestion patterns on the corridor are primarily driven by recurrent demand and time-of-day effects rather than seasonal fluctuations.

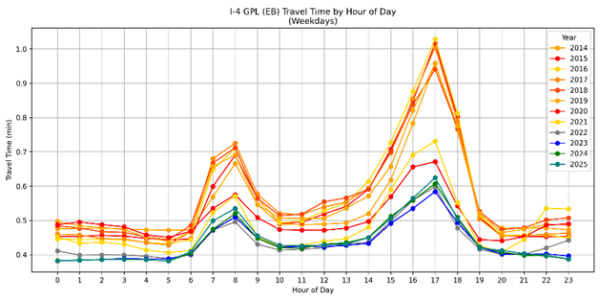


Figure 36. I4 GPL (EB) - Average Hourly Travel Time by Year

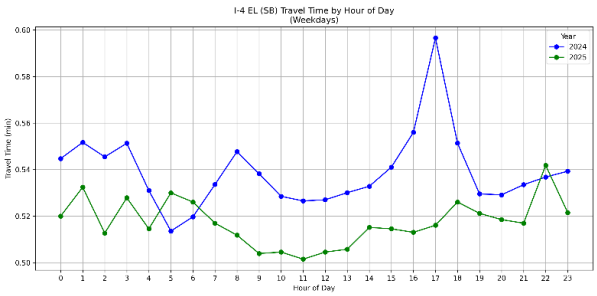


Figure 37. I-4 EL (NB) - Average Hourly Travel Time by Year

Additionally, results presented in **Figure 37** highlight that the Express Lanes demonstrate consistently lower and more stable travel times throughout the day, with noticeably dampened peak-period spikes. Following the full opening of the I-4 Ultimate Express Lanes in 2022, the divergence between EL and GPL performance becomes more evident, suggesting that the Express Lanes are effectively absorbing peak-period demand and providing improved travel time reliability. While absolute travel time differences remain modest due to the relatively short corridor length, the reduced variability and flatter hourly profiles in the Express Lanes highlight their

operational value, particularly for time-sensitive trips and freight movements exposed to extended peak congestion on the general-purpose lanes.

2.3.1.2 I-95

The results presented in **Figure 40** illustrate the average weekday travel time by hour for the I-95 general-purpose lanes over multiple years. Interpreting a before-and-after Express Lanes effect using this aggregate representation is inherently challenging, as the I-95 corridor includes multiple Express Lane segments that were implemented in different phases, locations, and time periods. As a result, corridor-wide averages tend to mask localized operational impacts that may occur near individual Express Lane access points or managed segments.

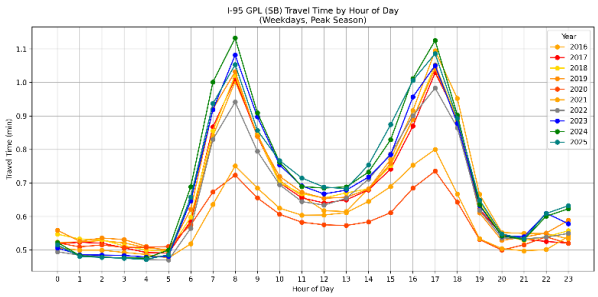


Figure 38. I95 GPL (SB) - Average Hourly Travel Time by Year (Peak Season)

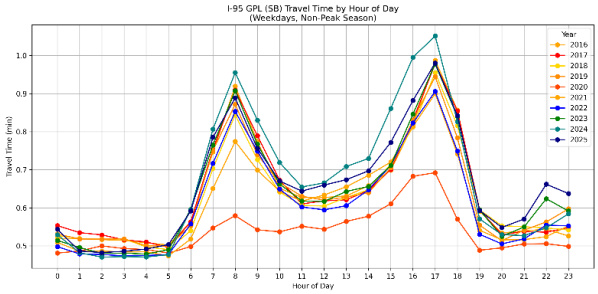


Figure 39. I95 GPL (SB) - Average Hourly Travel Time by Year (Non-Peak Season)

Despite this limitation, a gradual increase in average travel times is observed across several peak and shoulder periods in the later years, suggesting that overall traffic demand on I-95 continues to grow and, in some periods, appears to exceed the capacity of the existing infrastructure. This trend persists even though multiple traffic management and operational strategies have been implemented along the corridor. Importantly, however, the observed increases are not severe or abrupt, indicating that while congestion pressures are intensifying, the system has not experienced a disproportionate degradation in performance.

Importantly, as illustrated in **Figure 38** and **Figure 39**, seasonality does not appear to affect travel times in a statistically significant manner. The observed hourly travel time profiles remain largely consistent between peak and non-peak seasons, indicating that congestion patterns on the corridor are primarily driven by recurrent demand and time-of-day effects rather than seasonal fluctuations.

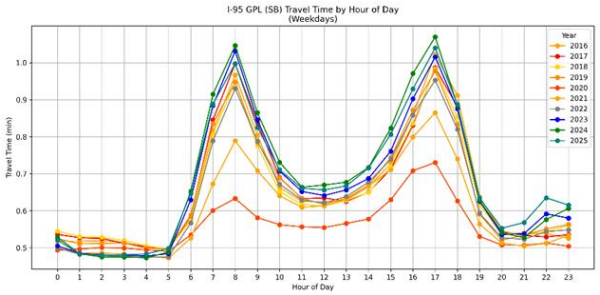


Figure 40. I95 GPL (SB) - Average Hourly Travel Time by Year

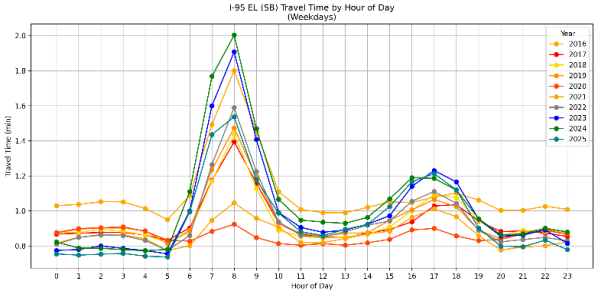


Figure 41. I95 EL (SB) - Average Hourly Travel Time by Year

Results presented in **Figure 41** highlight that the Express Lanes show higher but more stable and controlled travel times, especially during peak periods. More specifically, the EL curves demonstrate smoother interannual patterns and less volatility outside peak hours, suggesting improved predictability. More specifically, Express Lanes experience a noticeable deterioration in travel times during the morning peak. However, during the remainder of the day they maintain more stable average travel times. Importantly, because I-95 Express Lanes were implemented in multiple phases across different segments, their systemwide impact is not fully captured in an aggregated corridor-level GPL comparison. As a result, while direct one-to-one travel time reductions are not always visible in these plots, the figures collectively indicate that Express Lanes contribute to greater travel time reliability and congestion management, particularly during peak periods when GPL performance deteriorates most.

2.3.1.3 I-295

Results presented on **Figure 44**, the before-and-after comparison for I-295 East Beltway general-purpose lanes suggests a measurable but nuanced impact following the opening of the Express Lanes in 2022. In the pre-implementation years, the GPLs exhibit pronounced morning and afternoon peak spikes, with peak-hour travel times consistently exceeding off-peak levels, indicating recurrent congestion during commuter and freight activity periods. After the Express Lanes became available to motorists, the GPL travel-time profiles for subsequent years show a modest flattening of these peak spikes, particularly during the afternoon peak, along with slightly reduced peak magnitudes and improved stability across adjacent hours.

While congestion is not eliminated, and peak-period increases are still evident, the post-2022 patterns suggest that Express Lanes have helped absorb a portion of peak demand, contributing to marginal improvements in GPL travel time reliability. Importantly, the overall temporal structure of demand remains consistent, indicating that Express Lanes have moderated congestion intensity rather than fundamentally altering travel behavior. From a freight-mobility perspective, these modest reductions and smoother peak profiles are operationally meaningful, as they can potentially reduce extreme delays and improve travel time reliability for truck operators.

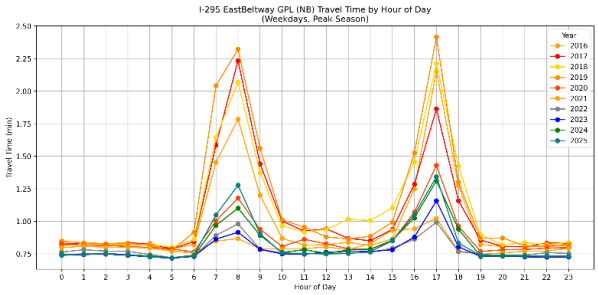


Figure 42. I295 GPL (NB) - Average Hourly Travel Time by Year (Peak Season)

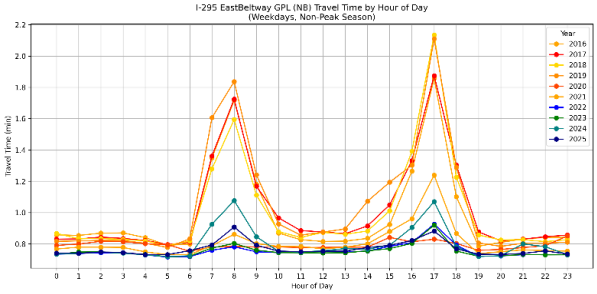


Figure 43. I295 GPL (NB) - Average Hourly Travel Time by Year (Non-Peak Season)

In addition, the results presented in **Figure 42** and **Figure 43** indicate that seasonality does have a noticeable impact on travel times, particularly during the morning peak period. During the peak season in the pre–Express Lane implementation era, higher travel times are observed, reflecting increased demand and heightened congestion. However, following the implementation of the Express Lane facilities, commuters appear to experience improved travel time reliability, with reduced peak-period variability and more stable morning travel times across seasons. This suggests that the Express Lanes have helped mitigate seasonal congestion pressures, especially during the most demand-sensitive morning hours.

Results presented in **Figure 45**, highlight that the Express Lane travel times on the I-295 East Beltway are consistent with expected managed lane performance and align well when compared to the General Purpose Lanes. The Express Lanes exhibit relatively low and stable travel times throughout the day, indicating near free-flow operating conditions and limited sensitivity to peak-period congestion. In contrast, the General Purpose Lanes display pronounced morning and afternoon peaks, reflecting recurring congestion patterns. The clear separation between Express Lane and GPL travel times during peak hours demonstrates the effectiveness of the Express Lanes in maintaining travel time reliability.

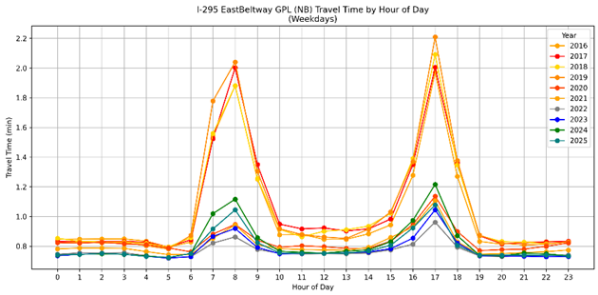


Figure 44. I-4 GPL (NB) - Average Hourly Travel Time by Year

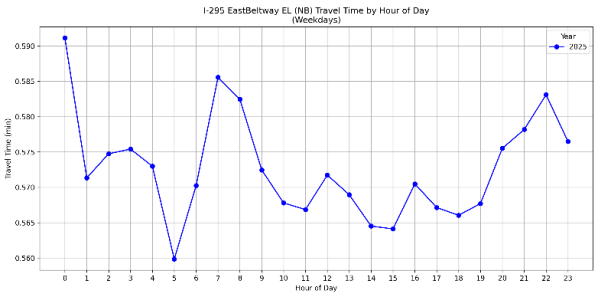


Figure 45. I-4 EL (NB) - Average Hourly Travel Time by Year

2.3.2 Average Travel Speeds

2.3.2.1 I-4

Results presented on **Figure 48** reveal distinct differences between the pre- and post-Express Lane implementation periods. More specifically, prior to 2022, weekday speeds exhibit pronounced reductions during both the morning and afternoon peak periods, with the most severe speed degradation occurring during the PM peak (approximately 4:00–6:00 PM), reflecting recurring congestion and limited operational flexibility. Following the introduction of the I-4 Ultimate Express Lanes in 2022, the GPL speed profiles show modest but consistent improvements, particularly during peak periods, along with reduced variability across hours of the day. While peak-hour speed drops persist, indicating that overall demand continues to stress the corridor, the post-implementation period demonstrates slightly higher average speeds and a more stable off-peak recovery pattern. These findings suggest that the Express Lanes have contributed to improved traffic flow in the general-purpose lanes by redistributing demand during congested periods, even though they have not fully eliminated peak-period congestion on this heavily traveled corridor

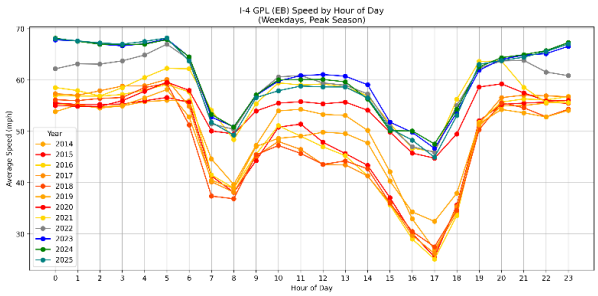


Figure 46. I4 GPL (EB) - Average Hourly Speed by Year (Peak Season)

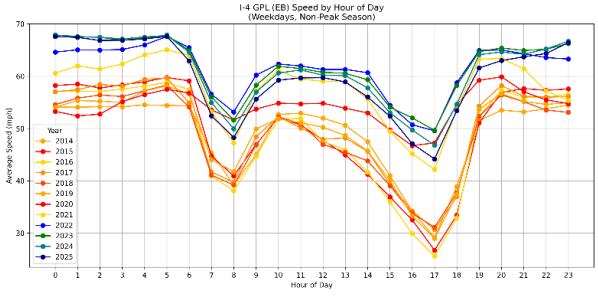


Figure 47. I4 EL (EB) - Average Hourly Speed by Year

Also, as illustrated in **Figure 46** and **Figure 47**, seasonality does not appear to affect speed profiles in a statistically significant manner. The hourly speed profiles observed are primarily driven by recurrent demand and time-of-day effects rather than seasonal fluctuations

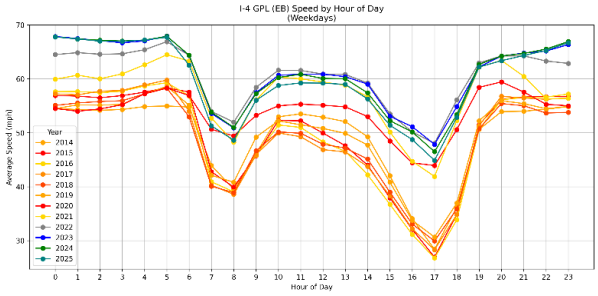


Figure 48. I4 GPL (EB) - Average Hourly Speed by Year

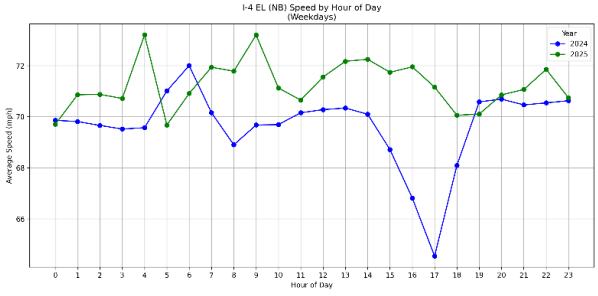


Figure 49. I4 EL (NB) - Average Hourly Speed by Year

Results presented on **Figure 49** show that Express Lanes consistently maintain higher and more stable speeds throughout the day, generally remaining near or above 70 mph, even during peak congestion periods. While GPL speeds continue to experience significant peak-period degradation after 2022, the Express Lanes demonstrate a clear ability to preserve free-flow or near free-flow conditions.

2.3.2.2 I-95

Results presented on **Figure 52**, indicate that GPL speeds drop sharply during the morning and afternoon peaks, particularly between approximately 7–9 AM and 3–6 PM, indicating sustained demand pressures on the corridor. While Express Lanes were introduced in multiple phases along different segments of I-95 over an extended time period, this phased rollout makes it difficult to clearly isolate systemwide speed improvements in a corridor-level GPL comparison. Any localized benefits associated with Express Lane implementation are likely diluted when aggregated across the full I-95 segment shown in this figure. As a result, although some post-implementation years show modest stabilization in off-peak speeds, overall GPL performance remains dominated by high traffic demand that continues to exceed available capacity.

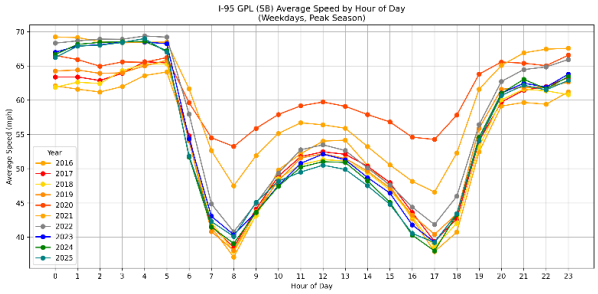


Figure 50. I95 GPL (SB) - Average Hourly Speed by Year (Peak Season)

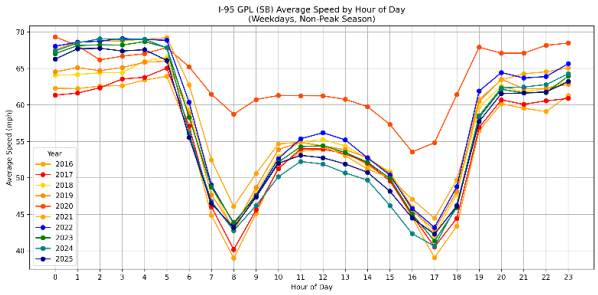


Figure 51. I95 GPL (SB) - Average Hourly Speed by Year (Non-Peak Season)

Additionally, as illustrated in **Figure 50** and **Figure 51**, although minor differences exist, seasonality does not appear to affect travel speeds in a statistically significant manner.

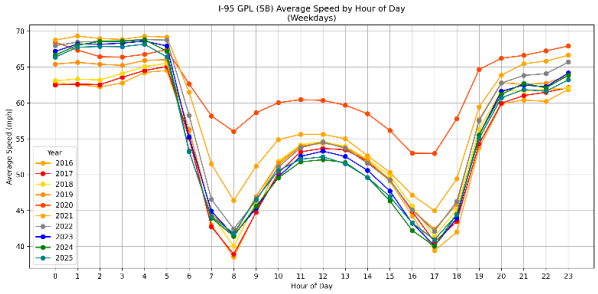


Figure 52. I95 GPL (SB) - Average Hourly Speed by Year

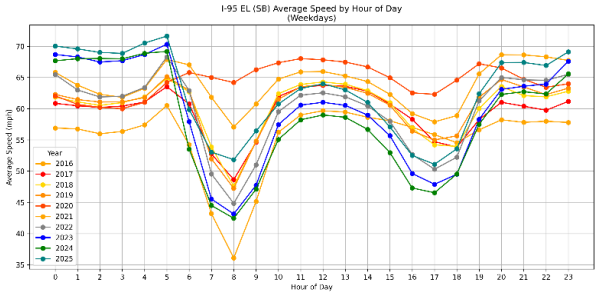


Figure 53. I95 EL (SB) - Average Hourly Speed by Year

Finally, results presented in **Figure 53**, indicate that the Express Lanes maintain higher and more stable speeds throughout the day, with smoother speed reductions during peak periods. While some

variability remains in the EL speed profiles, particularly during the most congested hours, the magnitude of speed loss is substantially smaller than in the GPLs. This indicates that the Express Lanes are effectively preserving near–free-flow conditions when the adjacent GPLs experience heavy congestion. The divergence between GPL and EL performance is most evident during the PM peak, when GPL speeds reach their lowest levels while EL speeds remain comparatively elevated.

Another important finding is that, in contrast to the General Purpose Lanes, the Express Lanes exhibit a clear improvement in average speeds over time. As additional Express Lane segments have been introduced and operational and pricing policies have matured, the Express Lanes increasingly maintain higher and more stable speeds. This trend suggests that the effectiveness of the managed lane system improves as network continuity increases and management strategies become more refined, reinforcing the role of Express Lanes as a reliable, high-performance alternative under growing traffic demand.

2.3.2.3 I-295

Results presented on **Figure 56** highlight a clear distinction between the pre- and post-Express Lane implementation periods. More specifically, prior to Express Lane availability (2016–2021), GPL speeds experienced pronounced degradation during both the morning and afternoon peak hours, with sharp drops, particularly around 7–9 AM and 4–6 PM, indicating recurring congestion and limited peak-period resilience. Following the introduction of the Express Lanes in 2022, GPL speeds exhibit noticeable stabilization and improvement, especially during peak periods. While peak-hour speed reductions remain present, their severity is reduced, and post-implementation years consistently show higher average speeds and smoother hourly profiles compared to the pre-implementation era.

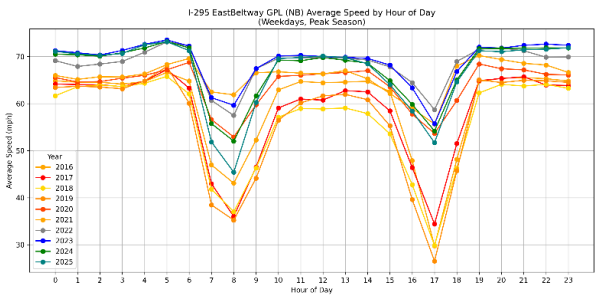


Figure 54. I295 GPL (NB) - Average Hourly Speed by Year (Peak Season)

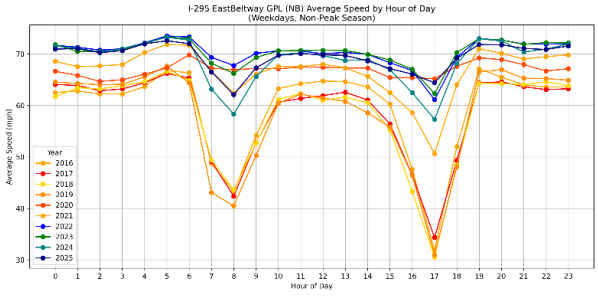


Figure 55. I295 GPL (NB) - Average Hourly Speed by Year (Non-Peak Season)

Additionally, with respect to the impact of seasonality, **Figure 54** and **Figure 55** indicate that during non-peak seasons the magnitude of speed reductions is less pronounced, particularly during congested periods. This suggests that lower overall demand during non-peak months contributes to more stable operating conditions, and that enhanced travel time reliability is more strongly associated with non-peak season trips.

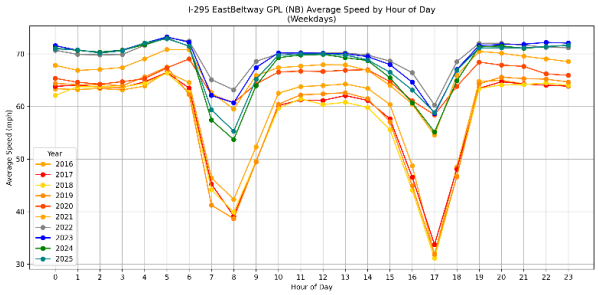


Figure 56. I295 GPL (NB) - Average Hourly Speed by Year

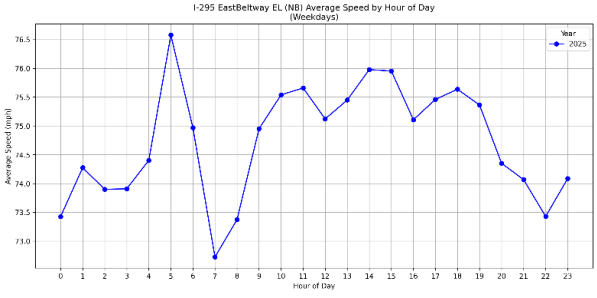


Figure 57. I295 EL (NB) - Average Hourly Speed by Year

Results presented in **Figure 57** indicate that the Express Lanes maintain consistently higher and more stable speeds throughout the day, with only minor reductions during peak periods, as EL speeds remain close to free-flow conditions even when GPL speeds deteriorate substantially during the AM and PM peaks. These findings indicate that the Express Lanes effectively provide improved travel time reliability and higher operating speeds, particularly during periods of peak demand.

2.3.3 Average Delay Times

For the purposes of this research, and given limitations in data availability, average delay was estimated using a data-driven proxy defined as the excess of observed hourly travel time relative to free-flow conditions. Free-flow travel time was approximated using the 20th percentile of nighttime travel times (1:00–4:00 AM), a period characterized by minimal congestion. This approach minimizes the influence of congestion while avoiding sensitivity to extreme minimum observations, providing a robust and consistent baseline for delay estimation.

2.3.3.1 I-4

Results presented on **Figure 58** show a clear before-and-after contrast associated with the implementation of Express Lanes. In the pre-implementation period (2014–2021), GPL delays are consistently higher during both the AM peak (around 7–9 AM) and, more prominently, the PM peak (around 3–6 PM). After 2022, a noticeable reduction in average delays is observed across most hours of the day, particularly during peak periods. While congestion patterns persist—especially in the PM peak, the magnitude of delays in the post-implementation years (2022–2025) is lower and more stable, indicating improved operational performance and reliability in the GPLs. This suggests that the introduction of Express Lanes likely absorbed a portion of peak-period demand and helped moderate delay growth in adjacent GPLs, even though peak congestion has not been entirely eliminated.

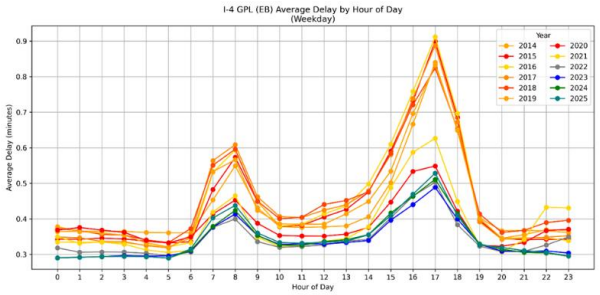


Figure 58. **I-4 GPL (EB) - Estimated Average Hourly Delay (min)**

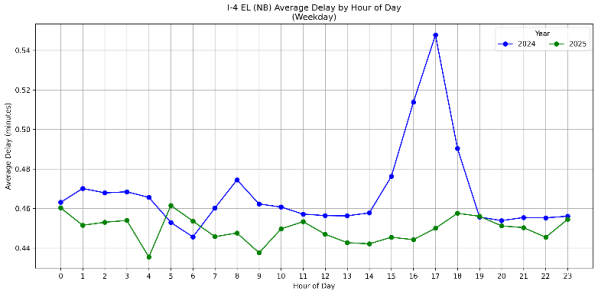


Figure 59. I4 EL (NB) - Estimated Average Hourly Delay (min)

In contrast to the GPL results, the EL on I-4 exhibit a significantly more stable and lower delay profile throughout the day. As shown in the **Figure 59**, average EL delays remain tightly bounded across most hours, with only a modest increase during the PM peak (around 4–6 PM). Even during this most congested period, EL delays are substantially lower and less volatile than those observed in the GPLs, indicating stronger reliability performance. The year (2025) further demonstrates slightly reduced and smoother delay patterns compared to 2024, suggesting operational learning, improved pricing and lane-management strategies, or better user adaptation over time. Overall, while GPLs continue to experience pronounced peak-period delays, the ELs successfully maintain controlled delay levels, reinforcing their role as a reliability-focused facility rather than merely a speed enhancement.

2.3.3.2 I-95

Results presented in **Figure 60** indicate that GPL average delay increases sharply during both the morning and afternoon peak periods—approximately 7:00–9:00 AM and 3:00–6:00 PM—reflecting sustained demand pressures along the corridor. Although Express Lanes were introduced on I-95, their implementation occurred in multiple phases across different segments and over an extended time horizon. This phased rollout makes it challenging to isolate clear, systemwide improvements in GPL performance using a corridor-level comparison. Any localized benefits associated with Express Lane operations are likely diluted when aggregated across the full I-95 segment shown in the figure.

As shown in the **Figure 61** , EL delays remain substantially lower and more stable throughout the day, even during peak hours. Although ELs still experience some increase in delay during the most congested periods, the magnitude of these increases is notably smaller than in the GPLs, indicating improved travel time reliability. This contrast suggests that the managed nature of the Els, through access control, pricing, and operational strategies, which essentially helps buffer peak-period congestion effects, whereas GPL performance continues to be dominated by corridor-wide demand pressures.

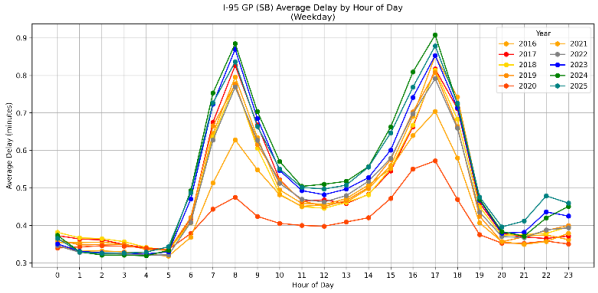


Figure 60. **I95 GPL (SB) - Estimated Average Hourly Delay (min)**

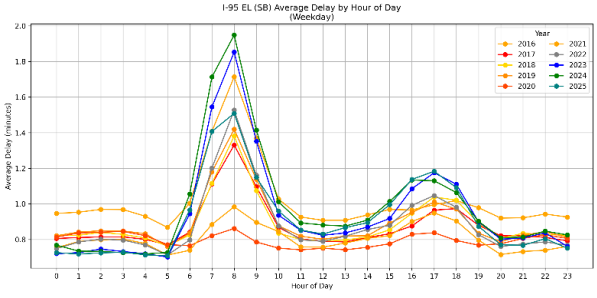


Figure 61. I95 EL (SB) - Estimated Average Hourly Delay (min)

2.3.3.3 I-295

Results presented in **Figure 62** indicate a clear contrast in GPL delay patterns before and after the implementation of the Express Lanes in 2022. In the pre-implementation period, GPL delays on I-295 increase sharply during both the morning (around 7–9 AM) and afternoon (approximately 3–6 PM) peak periods, with pronounced spikes that reflect recurrent congestion and limited operational flexibility. However, following the introduction of the Express Lanes in 2022, GPL delays during peak hours remain evident but are generally lower in magnitude and more contained, particularly in the morning peak. Post-implementation years show a noticeable moderation of extreme delay values and a flatter delay profile outside peak periods, suggesting some indirect relief to GPL operations.

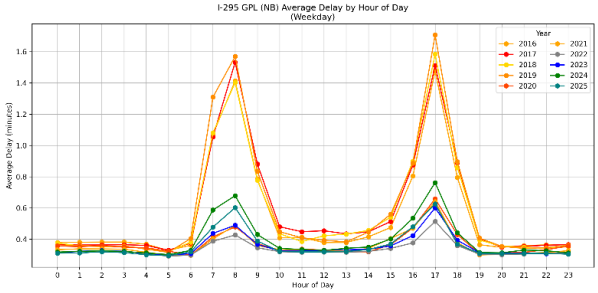


Figure 62. **I295 GPL (NB) - Estimated Average Hourly Delay (min)**

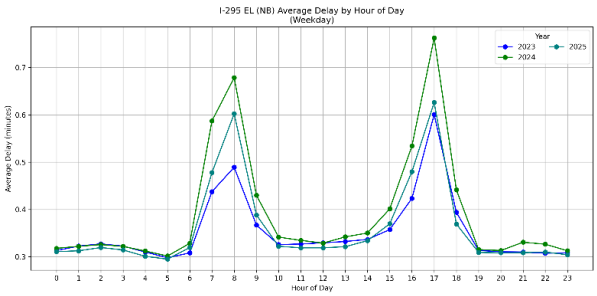


Figure 63. I295 EL (NB) - Estimated Average Hourly Delay (min)

On the other hand, results presented in **Figure 63** indicate that EL delay profiles demonstrate enhanced metrics compared to the GPLs. While GPL average delay exhibits sharp and pronounced peaks during both the morning (around 7–9 AM) and afternoon (approximately 3–6 PM) periods, the ELs maintain substantially lower and more stable delays across the day. Even during peak hours, EL delays remain comparatively modest and exhibit less interannual variability, particularly in the post-2022 period.

2.3.4 Crash Rates

For the crash analysis, normalized hourly crash rates were evaluated across multiple years before and after the implementation of Express Lanes. This normalization allows for a consistent comparison over time by accounting for differences in exposure and traffic activity. The objective of this analysis is to assess whether the introduction of Express Lanes is associated with observable changes in crash occurrence patterns and overall safety performance along the studied corridors.

2.3.4.1 I-4

Results presented in **Figure 64**, highlight that there is a modest reduction in crash frequency following the implementation of Express Lanes. Across most daytime hours, particularly during the morning (approximately 6–9 AM) and afternoon peak periods (approximately 3–6 PM), the post-implementation profile consistently lies below the pre-implementation curve. This suggests an overall reduction of peak-hour crash occurrence after Express Lane deployment. However, the temporal pattern of crashes remains largely unchanged, with pronounced peaks still aligned with periods of highest traffic demand. This consistency implies that while Express Lanes may contribute to incremental safety benefits, potentially through improved traffic flow, reduced speed variability, or managed demand, they do not fundamentally alter the underlying demand-driven crash dynamics of the corridor.

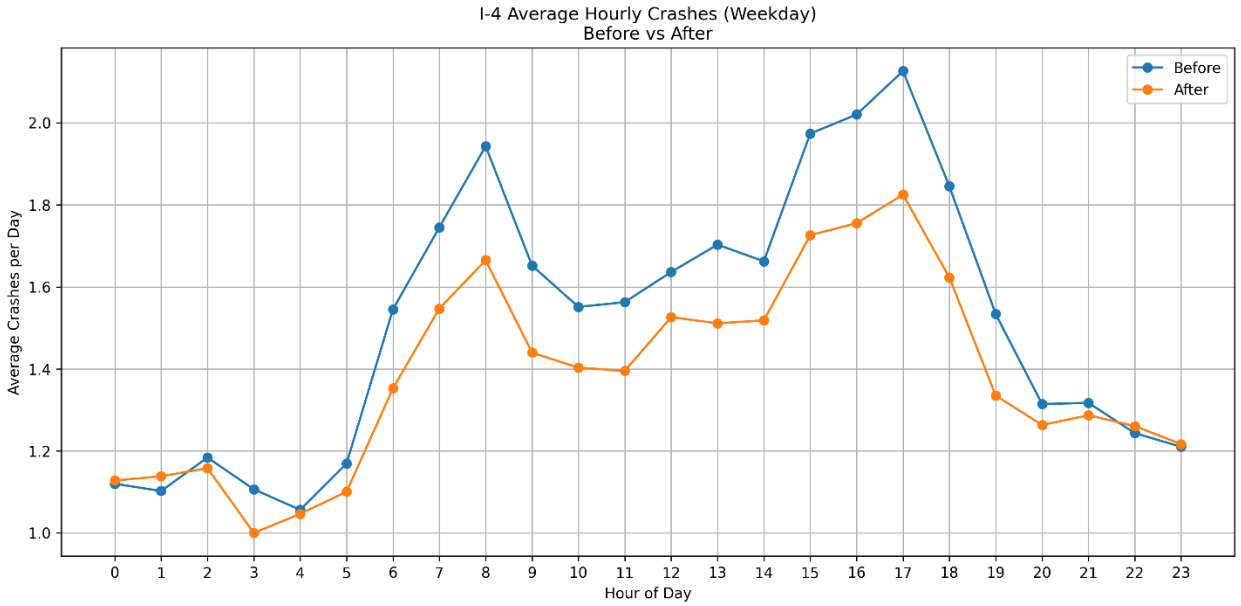


Figure 64. I4 - Average Hourly Crashes

2.3.4.2 I-95

Results for the I-95 average hourly crashes do not reveal clear or robust before–after patterns associated with the implementation of Express Lanes. The observed variation is largely driven by overall traffic exposure, with higher crash frequencies occurring during daytime hours when traffic volumes are highest and near-zero values during late night periods. Given the limited temporal

resolution, the small magnitude of differences, and the phased implementation of Express Lanes along multiple I-95 segments over several years, our current i-95 crash analysis do not support a defensible outcomes regarding systematic safety impacts attributable to Express Lane deployment. To avoid presenting potentially misleading conclusions, no claims regarding crash reductions or increases are drawn in this section. Nevertheless, the research team will continue to examine crash data using alternative normalizations, spatial disaggregation, and severity-based metrics to determine whether more meaningful safety patterns emerge in future analyses.

2.3.4.3 I-295

Results presented in **Figure 65**, indicate that while the post-implementation curve shows slight reductions during some hours and modest smoothing of extreme values, these differences are not statistically significant to suggest a substantial corridor-wide safety shift. As a result, any safety benefits associated with Express Lanes are more likely to be localized or incremental rather than clearly detectable at the systemwide hourly level we focused.

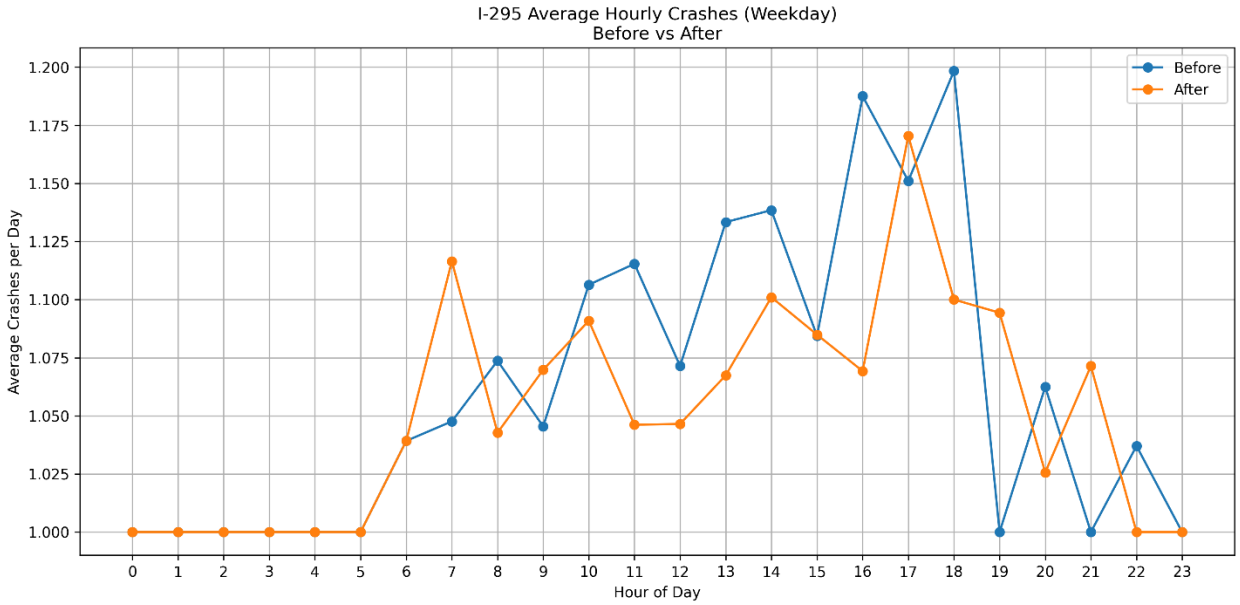


Figure 65. I295 - Average Hourly Crashes

2.3.5 Travel Time Reliability

For the purposes of this research, travel time reliability was quantified using hour-based variability metrics derived from observed hourly travel times. Reliability was evaluated using the coefficient of variation to capture relative dispersion across time, along with percentile-based spread measures, including the interquartile range (IQR) and the difference between the 95th percentile and the median travel time. Together, these metrics characterize both typical variability and exposure to extreme travel time conditions, providing a robust assessment of reliability under data-constrained conditions.

2.3.5.1 I-4

Results presented in **Figure 66** and **Figure 67** indicate a clear evolution in travel time reliability for the I-4 GPL (EB). The coefficient of variation generally increased from 2014 through 2019–2021, reflecting growing relative variability in travel times during that period. More specifically, a noticeable improvement occurs after 2021, with CV-TT dropping in 2022 and remaining lower and more stable through 2025, suggesting enhanced reliability. This pattern is reinforced by the percentile-based metrics, as both the interquartile range and the P95-median spread decline substantially after 2021, indicating reduced dispersion and fewer extreme delay events. Thus, the results suggest that while variability intensified in the pre-implementation years, post-2022 conditions might exhibit more stable and predictable travel times on the GPLs.

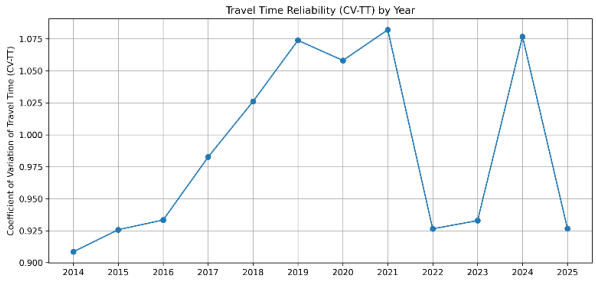


***Figure 66.* I-4 GPL (EB) – Travel Time Reliability – CV-TT**

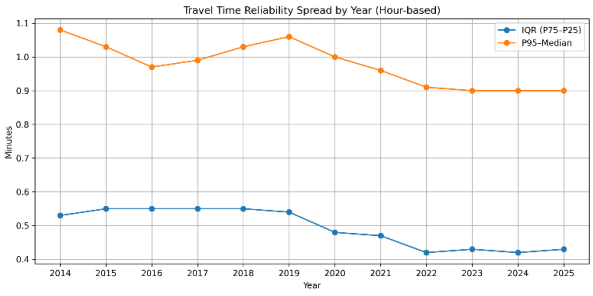


Figure 67. I4 GPL (EB) – Travel Time Reliability – IQR&P95

2.3.5.2 I-95

Results presented in **Figure 68** and **Figure 69** indicate a gradual deterioration in reliability over the analysis period. The coefficient of variation of travel time shows an overall upward trend, particularly after 2021, reflecting increasing relative variability in hourly travel times as congestion intensifies. This pattern is reinforced by the percentile-based measures: while the interquartile range remains relatively stable, suggesting limited changes in typical day-to-day variability, the widening gap between the 95th percentile and the median highlights growing exposure to extreme delays during peak periods.

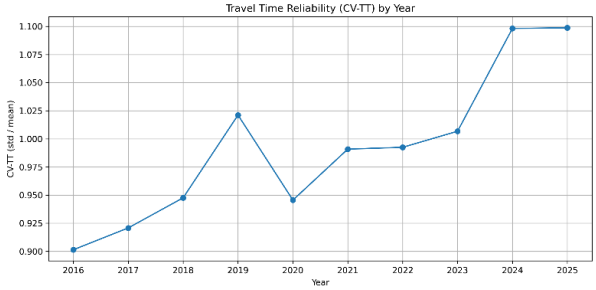


***Figure 68.* I95 GPL (SB) - Travel Time Reliability – CV-TT**

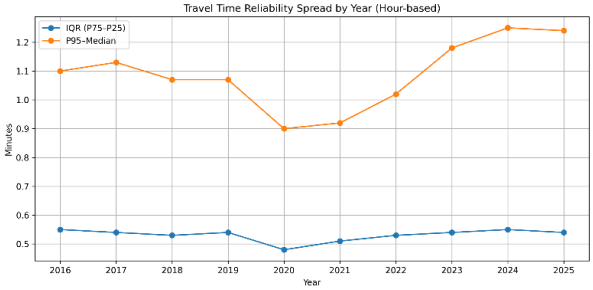


Figure 69. I95 GPL (SB) - Travel Time Reliability – IQR&P95

2.3.5.3 I-295

Results presented in **Figure 70** and **Figure 71**, indicate a significant improvement in reliability following 2020. As shown by the CV-TT, variability relative to mean travel time declines substantially after 2019, reaching its lowest levels around 2021–2022, which suggests more stable and predictable travel conditions. This trend is supported by the percentile-based measures, as both the interquartile range and the P95–median spread decrease sharply after 2019, indicating a reduction in both typical variability and extreme delay events. Although a modest increase in variability is observed in 2024, overall post-implementation years remain significantly more reliable than the pre-2020 period. Thus, these results should suggest that travel time reliability on I-295 GPL improved in the later years.

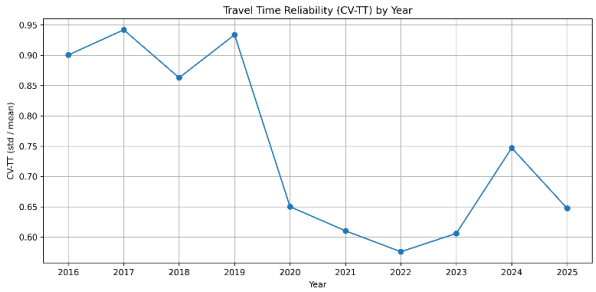


***Figure 70.* I295 GPL (NB) - Travel Time Reliability – CV-TT**

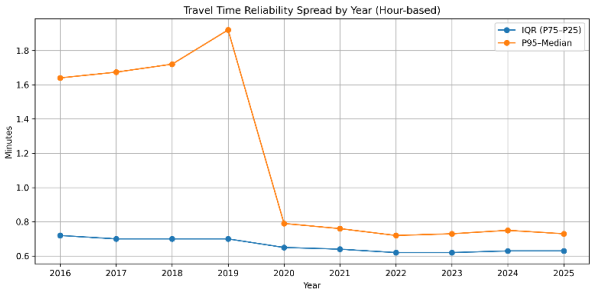


Figure 71. I295 EL (NB) - Travel Time Reliability – IQR&P95

2.3.6 Travel Time Savings

Due to data limitations, travel time savings between General Purpose Lanes and Express Lanes cannot be reported defensibly in this version of the report. Specifically, the available travel time series are derived from different sets of Traffic Message Channel segments for GPLs and ELs, and these segment sets do not fully overlap spatially. Because the GPL and EL measurements are not strictly matched over the same roadway limits, a direct one-to-one comparison would likely introduce bias and could misrepresent user-level benefits. Therefore, to avoid providing potentially misleading results, travel time savings are not presented here. The research team will evaluate alternative matching and corridor-reconciliation approaches and will provide a more detailed and accurate savings analysis as soon as feasible.

2.3.7 Economic Benefits

Based on the defined scope of work, the estimation of economic benefits is intended to rely primarily on quantified travel time savings. At this stage, however, the research team is unable to produce defensible travel time savings estimates due to data limitations, which affects the direct execution of this component of the analysis. As a result, this element of the scope cannot be fully addressed in the current reporting period. The research team is actively working to resolve the identified data issues associated with travel time savings estimation and, in parallel, is evaluating alternative, methodologically sound approaches for assessing the economic benefits of Express

Lane implementation (e.g., using delay and reliability-based performance measures). Updated results and refined benefit estimates will be provided as soon as these issues are resolved.

2.3.8 Environmental Benefits

Results presented in the following tables have been sourced from RITIS.org and provide consistent and reliable statistics. The results exhibit a clear and recurring pattern of reduced energy consumption and vehicle miles traveled (VMT) following the implementation of Express Lanes. These changes are primarily attributed to improved traffic flow efficiency and a reduction in congestion-related inefficiencies, rather than a decrease in overall travel demand.

From an energy perspective, stop-and-go traffic represents one of the most energy-intensive operating conditions. Even modest increases in average speed can yield disproportionate energy savings when accompanied by reduced speed variability. The results indicate that, following Express Lane implementation, there is a consistent reduction in both total energy consumption and energy intensity (measured in BTUs per VMT) across all days of the week. These improvements reflect smoother traffic flow, lower acceleration–deceleration cycles, and vehicle operation closer to energy-optimal speed ranges.

Importantly, the observed benefits extend beyond the Express Lanes themselves, suggesting corridor-wide congestion mitigation effects rather than isolated, lane-specific improvements.

2.3.8.1 I-4

The environmental analysis for the I-4 corridor indicates consistent improvements following the implementation of Express Lanes. More specifically, results presented in **Table 18** & **Table 19** and **Figure 72** - **Figure 75**, indicate that the daily energy consumption, measured in BTUs, decreased across all days of the week, while VMT remained largely stable, with only minor reductions observed. At the same time, energy consumption per vehicle-mile traveled (energy intensity) showed a consistent decline, indicating more efficient traffic operations. Similarly, CO_2 emissions per VMT decreased uniformly across both weekdays and weekends, reflecting a system-wide improvement in environmental performance associated with smoother traffic flow and reduced congestion.

Table 18. I-4 (Before EL) - Energy Consumption Metrics

Day of week	Energy use (BTUs)	VMT	Energy use / VMT (BTUs)	CO_2 / VMT (tons)
Sunday	501.88 B	113.32 M	4,429	3.90e-4
Monday	682.05 B	151.22 M	4,510	3.90e-4
Tuesday	684.57 B	151.22 M	4,527	3.90e-4
Wednesday	673.24 B	148.37 M	4,538	4.00e-4
Thursday	674.58 B	148.37 M	4,547	4.00e-4
Friday	706.78 B	155.40 M	4,548	4.00e-4
Saturday	568.85 B	127.51 M	4,461	3.90e-4

Table 19. I-4 (After EL) - Energy Consumption Metrics

Day of week	Energy use (BTUs)	VMT	Energy use / VMT (BTUs)	CO_2 / VMT (tons)
Sunday	495.25 B	112.83 M	4,389	3.80e-4
Monday	665.44 B	150.54 M	4,420	3.80e-4
Tuesday	666.91 B	150.54 M	4,430	3.80e-4
Wednesday	654.98 B	147.72 M	4,434	3.80e-4
Thursday	655.37 B	147.67 M	4,438	3.80e-4
Friday	686.25 B	154.75 M	4,435	3.80e-4
Saturday	558.54 B	126.94 M	4,400	3.80e-4

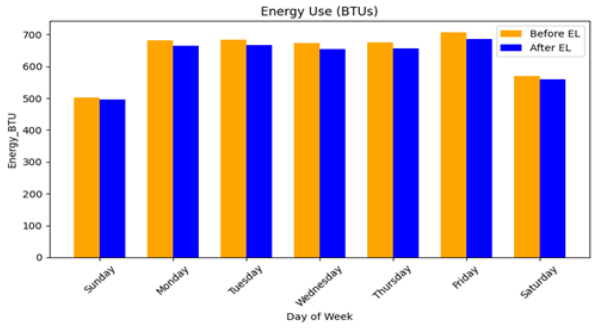


Figure 72. I-4 – Energy Use (BTUs)

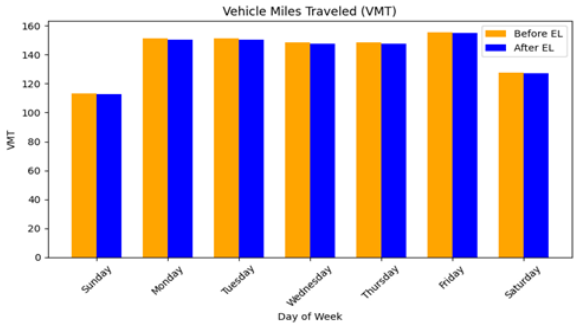


Figure 73. I-4 – Vehicles Miles Traveled (VMT)

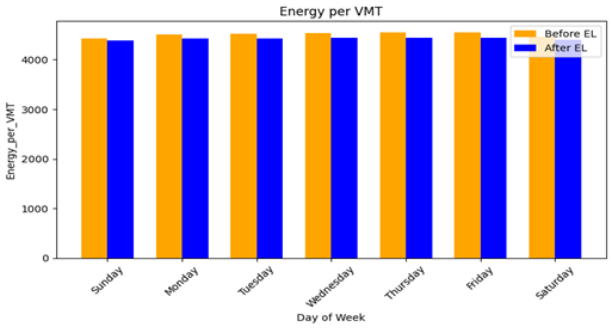


Figure 74. I-4 – Energy Use per VMT

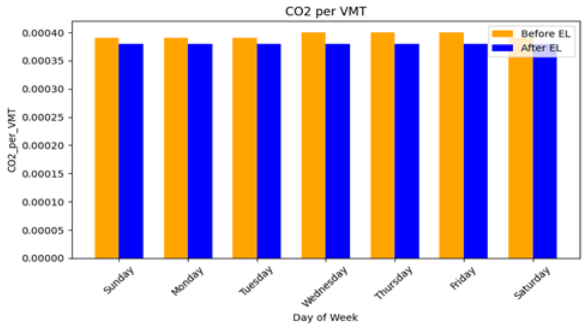


Figure 75. I-4 – CO2 per VMT

2.3.8.2 I-95

The environmental analysis for the I-95 corridor indicates mixed but overall efficiency-improving trends following the implementation of Express Lanes. More specifically, results presented in **Table 20** & **Table 21** and **Figure 76** - **Figure 79**, indicate that the total energy consumption, measured in BTUs, shows variation across the week, with reductions observed on weekends and slight increases during some weekdays, likely reflecting increased travel demand. VMT increase across most days, particularly on weekdays, suggesting higher corridor usage. Despite this, energy

consumption per vehicle-mile traveled (energy intensity) declines consistently across all days, indicating improved operational efficiency. Similarly, CO_2 emissions per VMT decrease across most days, especially on weekends and early weekdays, highlighting overall environmental performance improvements despite increased traffic volumes.

Table 20. I-95 (Before EL) - Energy Consumption Metrics

Day of week	Energy use (BTUs)	VMT	Energy use / VMT (BTUs)	CO2 / VMT (tons)
Sunday	1,650.80 B	364.50 M	4,529	3.90e-4
Monday	2,187.80 B	466.78 M	4,687	4.10e-4
Tuesday	2,117.90 B	468.77 M	4,731	4.10e-4
Wednesday	2,173.90 B	457.94 M	4,747	4.10e-4
Thursday	2,216.00 B	465.97 M	4,757	4.20e-4
Friday	2,345.00 B	491.42 M	4,766	4.20e-4
Saturday	1,837.80 B	402.91 M	4,561	3.90e-4

Table 21. I-95 (After EL) - Energy Consumption Metrics

Day of week	Energy use (BTUs)	VMT	Energy use / VMT (BTUs)	CO2 / VMT (tons)
Sunday	1,603.90 B	368.50 M	4,353	3.80e-4
Monday	2,218.20 B	491.77 M	4,511	4.00e-4
Tuesday	2,229.60 B	491.77 M	4,534	4.00e-4
Wednesday	2,191.20 B	482.42 M	4,542	4.10e-4
Thursday	2,197.00 B	482.50 M	4,553	4.10e-4
Friday	2,311.00 B	505.49 M	4,572	4.10e-4
Saturday	1,821.80 B	414.71 M	4,393	3.80e-4

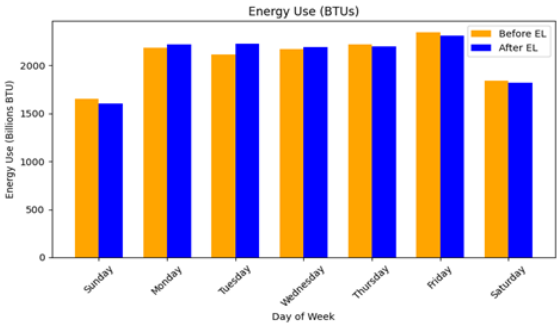


Figure 76. I-95 – Energy Use (BTUs)

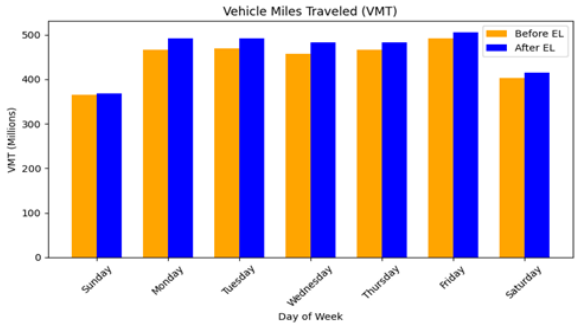


Figure 77. I-95 – Vehicles Miles Traveled (VMT)

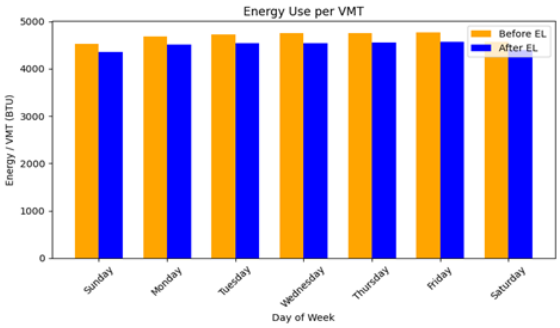


Figure 78. I-95 – Energy Use per VMT

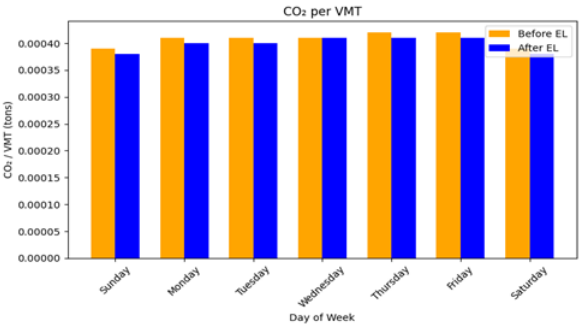


Figure 79. I-95 – CO2 per VMT

2.3.8.3 I-295

The environmental analysis for the I-295 corridor indicates clear improvements following the implementation of Express Lanes. Results presented in **Table 22** & **Table 23** and **Figure 80** - **Figure 83**, indicate that the total daily energy consumption, measured in BTUs, decreases across all days of the week, reflecting enhanced system efficiency. VMT remain largely stable, with only minor variations between the before and after periods. At the same time, energy consumption per vehicle-mile traveled (energy intensity) declines substantially across all days, indicating more efficient traffic operations. Similarly, CO_2 emissions per VMT decrease across most days, further supporting the conclusion that Express Lane implementation has contributed to improved environmental performance along the corridor.

Table 22. I-295 (Before EL) - Energy Consumption Metrics

Day of week	Energy use (BTUs)	VMT	Energy use / VMT (BTUs)	CO_2 / VMT (tons)
Sunday	48.48 B	11.01 M	4,404	3.90e-4
Monday	66.12 B	14.31 M	4,622	4.10e-4
Tuesday	67.83 B	14.40 M	4,711	4.30e-4
Wednesday	67.66 B	14.41 M	4,696	4.20e-4

Day of week	Energy use (BTUs)	VMT	Energy use / VMT (BTUs)	CO_2 / VMT (tons)
Thursday	68.17 B	14.36 M	4,746	4.30e-4
Friday	72.95 B	15.38 M	4,742	4.30e-4
Saturday	56.09 B	12.62 M	4,443	3.90e-4

Table 23. I-295 (After EL) - Energy Consumption Metrics

Day of week	Energy use (BTUs)	VMT	Energy use / VMT (BTUs)	CO_2 / VMT (tons)
Sunday	46.90 B	11.07 M	4,237	3.90e-4
Monday	60.38 B	14.22 M	4,248	3.80e-4
Tuesday	60.42 B	14.22 M	4,250	3.80e-4
Wednesday	60.40 B	14.22 M	4,249	3.80e-4
Thursday	60.56 B	14.22 M	4,260	3.80e-4
Friday	63.32 B	14.89 M	4,252	3.80e-4
Saturday	51.78 B	12.22 M	4,237	3.90e-4

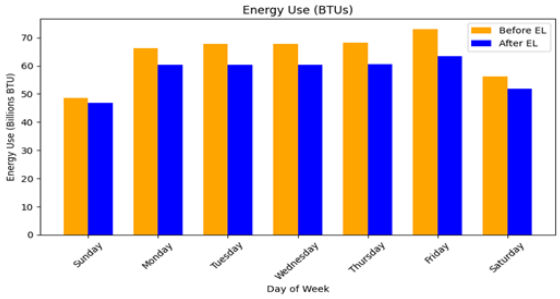


Figure 80. I-295 – Energy Use (BTUs)

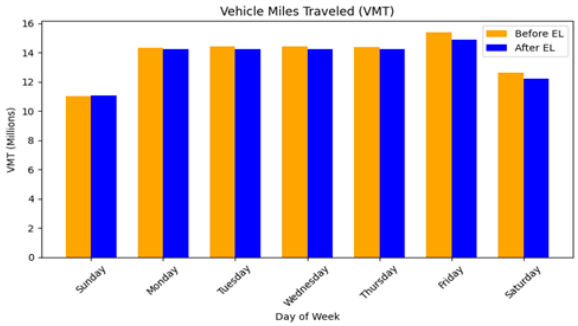


Figure 81. I-295 – Vehicles Miles Traveled (VMT)

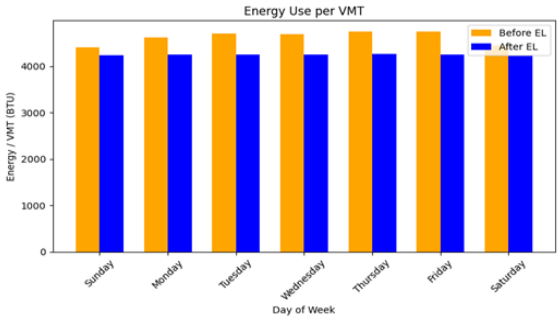


Figure 82. I-295 – Energy Use per VMT

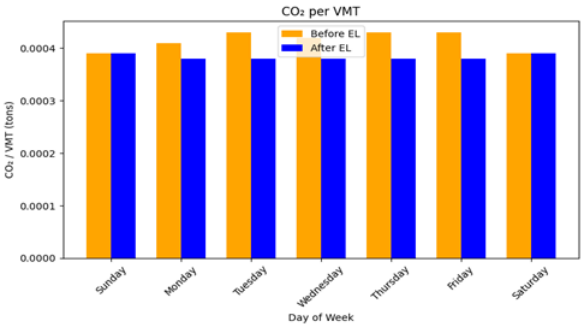


Figure 83. I-295 – CO2 per VMT

2.3.9 Challenges

Key limitations include differences in Traffic Message Channel (TMC) coverage and availability between General Purpose and Express Lanes, phased implementation of Express Lanes across corridors, and incomplete historical datasets for certain performance measures. These factors constrain the ability to conduct fully matched before–after and lane-to-lane comparisons, particularly for travel time savings and economic benefit estimation. Additionally, crash data exhibit substantial variability, which limits the ability to draw defensible safety inferences at the corridor level.

Additionally, another challenge is related to the data cleaning process for the South Florida section of I-95. Several segments experienced construction during different and sometimes overlapping periods, with conflicting timelines across available sources. Without access to the exact construction schedule, it is difficult to perform a thorough and reliable data cleaning process. Therefore, in the absence of a verified construction timeline, any results from the I-95 segment should be interpreted with caution.

2.3.10 Conclusions

For the purposes of this deliverable, the research team evaluated the performance and freight relevance of multiple Express Lane facilities. Based on their freight significance, strategic geographic location, and traffic demand characteristics, the corridors on I-95, I-4, and I-295 were identified as the most suitable for detailed analysis in this report. Their evaluation was conducted using a combination of traffic volume, travel time, delay, reliability, and safety-related metrics, derived primarily from RITIS and FDOT-supported datasets. Across all three corridors, results consistently confirm their strategic importance to Florida's freight system, given their high overall traffic demand, substantial truck activity, and direct connectivity to major seaports, airports, and intermodal logistics hubs.

The analysis indicates that Express Lanes provide clear operational and reliability benefits relative to General Purpose Lanes, particularly during peak periods. On I-95 and I-4, Express Lanes maintain lower delays, higher and more stable speeds, and improved travel time reliability, even as General Purpose Lanes remain heavily constrained by sustained demand. While corridor-wide GPL performance improvements are difficult to isolate, especially on I-95 due to phased implementation over multiple years, the Express Lanes consistently function as a reliability buffer, absorbing peak-period demand and mitigating extreme congestion conditions. On I-295, results suggest more noticeable stabilization in GPL delay and reliability following Express Lane implementation, reflecting the corridor's beltway function and freight-oriented traffic composition.

Reliability metrics further reinforce these findings. On I-4 and I-295, post-implementation years exhibit reduced variability and fewer extreme delay events in the GPLs, while I-95 continues to face growing reliability challenges driven by persistent demand pressures. Safety analysis based

on normalized hourly crash data does not reveal strong corridor-wide before–after effects attributable to Express Lanes; observed crash patterns remain largely exposure-driven. Accordingly, no causal safety claims are provided in this report.

Overall, the findings support the conclusion that Express Lanes on I-95, I-4, and I-295 deliver meaningful reliability and congestion-management benefits, particularly for time-sensitive freight movements, even when broader demand growth limits visible improvements in General Purpose Lane performance. These corridors therefore represent strong candidates for continued evaluation, refinement of managed lane strategies, and future investment aimed at improving freight mobility, system resilience, and operational efficiency across Florida's most critical transportation corridors.

Part III

VISSIM Model Development and Incident Analysis

I-95 Express Corridor — District 6 (Miami-Dade County)

Part III presents the adaptation and calibration checks of the VISSIM microsimulation model inherited from the I-95/State Road (SR) 9 Project Development and Environment (PD&E) Study and the incident-scenario analysis conducted as Deliverable 3. The analysis applies the microsimulation approach identified in Part I and is complementary to the empirical analysis in Part II. The modeled corridor is the I-95 Express Lane segment in FDOT District 6. Nine incident scenarios were evaluated in the AM and PM peak periods to assess the operational resilience of the express-lane and general-purpose lane network under varying levels of lane blockage.

1 Introduction

This study used the VISSIM model developed for the I-95/State Road (SR) 9 Project Development and Environment (PD&E) Study (Florida Department of Transportation, 2021), from south of SR 860/Miami Gardens Drive to north of the Broward County Line in Miami-Dade County, Florida. The model represents a managed-lanes corridor that includes general-purpose lanes, Express Lanes, ramps, and adjacent arterial connections within the project limits. The Research Team adapted and checked the inherited PD&E VISSIM model against available traffic observations. The available project record supports partial calibration, but a separate formal validation was not documented. The Research Team then developed and simulated a set of incident scenarios aligned with the objectives of the project.

The primary purpose of this analysis is to evaluate how different incident types and severities affect corridor operations within the project area. The incident scenarios were designed to represent a range of operational disruptions, including shoulder-side slowdowns, general-purpose lane obstructions, Express Lane incidents, ramp-area disruptions, access/egress-area incidents, rubbernecking effects, and long-duration events. These scenarios were implemented using time-windowed reduced-speed treatments within separate VISSIM scenario files, and the impact of each incident was measured against a no-incident reference run with the same random seed and the same VISSIM version.

In addition to network-wide performance measures such as delay, speed, travel time, and throughput, the analysis examines how the same incident scenarios affect passenger vehicles and heavy goods vehicles (HGVs). This vehicle-class comparison supports a more detailed understanding of incident impacts on freight operations, particularly under severe or long-duration disruptions. Overall, the study provides a scenario-based incident modeling framework for

assessing managed-lane corridor resilience and the relative operational impacts of different incident conditions within the I-95/SR 9 project area.

2 Project Area Description and Existing Conditions

The selected project area is located along SR 9/I-95 in northern Miami-Dade County, extending from the vicinity of the Golden Glades Interchange to north of CR 854/Ives Dairy Road, with additional consideration of adjacent interchanges and crossroads that influence traffic operations within the corridor. The primary interchange locations within or near the study area include: Figure 84 shows the project location.

1. SR 860/Miami Gardens Drive,
2. CR 854/Ives Dairy Road,
3. SR 858/Hallandale Beach Boulevard,
4. and the Golden Glades Interchange.

Based on FDOT Straight-Line Diagram information, the approximate centerline mileposts are:

5. MP 16.521 at CR 854/Ives Dairy Road,
6. MP 14.563 at SR 860/Miami Gardens Drive,
7. and MP 13.132 near the Golden Glades Interchange.

The approximate interchange spacing is:

8. 1.447 miles between SR 858/Hallandale Beach Boulevard and CR 854/Ives Dairy Road,
9. 1.958 miles between CR 854/Ives Dairy Road and SR 860/Miami Gardens Drive,
10. 1.431 miles between SR 860/Miami Gardens Drive and the Golden Glades Interchange.

2.1 Area Of Influence (AOI)

The Area of Influence (AOI) was defined based on the Interchange Access Request Users Guide (2025), which generally identifies the AOI in urban areas as extending to the on- and off-ramp gore points of the adjacent interchanges in each direction, as well as including signalized intersections within one-half mile of the interchange. For this study, the AOI was adjusted to reflect the specific operational characteristics of the SR 9/I-95 corridor and the surrounding roadway network. Along the SR 9/I-95 mainline, the AOI extends from the on- and off-ramp gore points to and from SR 7/US-441 at the southern limit to the off- and on-ramp gore points to and from SR 858/Hallandale Beach Boulevard at the northern limit.

Along SR 860/Miami Gardens Drive, the AOI extends from NE 2nd Avenue to NE 10th Avenue. This segment includes several key signalized intersections that directly influence interchange operations, including SR 860/Miami Gardens Drive at NE 2nd Avenue, NE 2nd Court, the SR 9/I-95 southbound ramp terminal/NE 6th Avenue/SR 915, the SR 9/I-95 northbound ramp terminal, and NE 10th Avenue. Along CR 854/Ives Dairy Road, the AOI extends from NE 15th Court to Highland Lakes Boulevard, including the intersections at NE 15th Court, NE 16th Avenue, the SR 9/I-95 southbound and northbound ramp terminals, and Highland Lakes Boulevard.

2.2 Land Use

The existing land use surrounding the study interchanges is mixed, with both residential and industrial activity located near the corridor. The west side of the SR 9/I-95 at SR 860/Miami Gardens Drive interchange is located within unincorporated Miami-Dade County, while the east side is located within the City of North Miami Beach. The SR 9/I-95 at CR 854/Ives Dairy Road interchange is located within unincorporated Miami-Dade County. Around SR 860/Miami Gardens Drive, the northeast and southeast quadrants are primarily residential, while the northwest and southwest quadrants are industrial. Similarly, around CR 854/Ives Dairy Road, the northeast and southeast quadrants are residential, while the northwest and southwest quadrants include industrial and communications, utilities, or terminal-related land uses.

Within the project limits, SR 9/I-95 functions as a limited-access freeway and Strategic Intermodal System facility. It is classified as an Urban Principal Arterial–Interstate, with an FDOT Access Management Classification of Class 1 and a posted speed limit of 55 mph. The corridor includes a combination of general-purpose lanes, express lanes, and auxiliary lanes, with the typical section varying by location. North of the CR 854/Ives Dairy Road interchange, the corridor generally includes four general-purpose lanes, one express lane, and auxiliary lanes in each direction. South of CR 854/Ives Dairy Road and through the SR 860/Miami Gardens Drive area, the lane configuration changes to accommodate express-lane ingress and egress movements, ramp connections, and auxiliary-lane needs. In several locations, the facility includes two express lanes in one or both directions, along with three to four general-purpose lanes and auxiliary lanes.

SR 860/Miami Gardens Drive, within the AOI from NE 2nd Avenue to NE 10th Avenue, functions as an arterial roadway. Its provisional context classification varies by location, with C3C – Suburban Commercial west of SR 9/I-95 and C3R – Suburban Residential east of SR 9/I-95. The roadway is functionally classified as an Urban Minor Arterial and has an FDOT Access Management Classification of Class 5. The posted speed limit is 40 mph west of NE 8th Street and 30 mph east of NE 8th Street. The typical section also varies across the interchange area. West of SR 9/I-95, SR 860/Miami Gardens Drive generally provides three eastbound lanes and three westbound lanes separated by a raised median. East of SR 9/I-95, the roadway generally provides two eastbound lanes and two westbound lanes separated by a raised median.

CR 854/Ives Dairy Road, within the AOI from NE 15th Court to Highland Lakes Boulevard, also functions as an arterial roadway. Since this facility is off the state highway system, its context and access management characteristics are generally comparable to those of SR 860/Miami Gardens Drive, with a suburban commercial character west of SR 9/I-95 and a suburban residential character east of SR 9/I-95. It is functionally classified as an Urban Minor Arterial, with access management conditions similar to FDOT Class 5. The posted speed limit is 40 mph. The typical section generally consists of three eastbound lanes and three westbound lanes separated by a raised median.

Overall, the project area represents a complex urban freeway environment with closely spaced interchanges, managed-lane access points, ramp terminal intersections, and adjacent arterial intersections. These characteristics make the corridor operationally sensitive to lane-changing behavior, ramp merge and diverge activity, express-lane access operations, arterial signal

operations, and congestion spillback between the freeway mainline and surrounding crossroads. Therefore, accurately defining the AOI and documenting the existing roadway, land use, and lane configuration conditions is essential for developing and evaluating the corridor simulation model.

2.3 Corridor Facility Structure

2.3.1 Modeled Corridor Overview

The model represents a sub-area microsimulation network centered on the I-95 managed lanes corridor in Miami-Dade County, Florida, in the vicinity of Miami Gardens Drive (MGD) and Ives Dairy Road / NW 183rd Street (IDR). As presented in Table 24, the model contains 374 link elements total, comprising four distinct facility types:

11. I-95 Interstate freeway General-Purpose (GP) lanes in the northbound and southbound directions;
12. I-95 Express Lane (EL) managed lane facilities in both directions; on- and off-ramp connections to the GP mainline at major interchanges; and at-grade arterial networks representing Miami Gardens Drive (EB and WB) and Ives Dairy Road (EB and WB). Additionally, approximately 200 connector link elements (link numbers 10000–10202) encode the lane-level geometry at merge, diverge, weave, and intersection approach locations.

Table 24. Facility Summary

Facility	Direction	Link No. Range	No. of Links	Lane Count Range	Notes
I-95 GP Freeway	NB	101–114	14	3–5	Mainline freeway links
I-95 GP Freeway	SB	201–216	16	3–6	Mainline freeway links
I-95 GP On/Off-Ramps	NB	151–160	10	1–1	Single-lane ramps at MGD, IDR, HBB, US441, EL
I-95 GP On/Off-Ramps	SB	251–259	9	1–2	Ramps at HBB, IDR, EL, MGD, US441

Table 24. Facility Summary (continued)

Facility	Direction	Link No. Range	No. of Links	Lane Count Range	Notes
I-95 Express Lane	NB	301–304	4	1–2	Separated EL facility; EL driving behaviors
I-95 Express Lane	SB	401–404	4	1–2	Separated EL facility; EL driving behaviors
Miami Gardens Drive	EB	501–564	16	2–4	Arterial including I-95 interchange connections
Miami Gardens Drive	WB	601–664	21	1–3	Arterial including I-95 interchange connections
Ives Dairy Road	EB	701–766	22	1–5	Arterial including I-95 interchange connections
Ives Dairy Road	WB	801–860	17	1–4	Arterial including I-95 interchange connections

2.3.2 General-Purpose Lane Configuration

2.3.2.1 NB GP Mainline

Data presented in Table 25 highlight that the I-95 NB GP facility is represented by 14 mainline freeway links (101–114), spanning the full study corridor from the US 441/SR 9/NW 7th Avenue area in the south to the Hallandale Beach Boulevard interchange in the north. Lane counts on the NB GP mainline range from 3 lanes (Links 101, 104, 106, 107) to 5 lanes (Links 109, 111, 113) at their widest, reflecting the varying geometry through weave and merge zones. The corridor passes through the Miami Gardens Drive interchange and the Ives Dairy Road interchange with associated lane changes at each interchange.

Table 25.NB GP Mainline Configuration

Link No.	Name	Lanes	Length (ft)	Behavior Type	Key Feature
101	101 (3)_I-95 NB GP	3	1,410	Freeway Basic	Corridor southern entry; VI#101
102	102 (5)_I-95 NB GP	5	534	Freeway Basic	Short widening near NW2ndAve
103	103 (4)_I-95 NB GP	4	2,421	Freeway Basic	Adjacent to EL access ramps 153/160
104	104 (3)_I-95 NB GP	3	2,024	Freeway Basic	DCP#56-58 at pos=381 m
105	105 (2)_I-95 NB GP	4	276	Freeway Basic	Label/lane count discrepancy
106	106 (3)_I-95 NB GP	3	861	Freeway Diverge/Merge	Near MGD interchange
107	107 (3)_I-95 NB GP	3	10,610	Freeway Basic	Long segment; DCP#26-28
108	108 (4)_I-95 NB GP	4	12,477	Freeway Weave	Weave zone south of IDR; DCP#102-105

Table 25. NB GP Mainline Configuration (continued)

Link No.	Name	Lanes	Length (ft)	Behavior Type	Key Feature
109	109 (5)_I-95 NB GP	5	18,081	Freeway Weave	Wide weave zone through IDR area; DCP#15-19, DCP#91-95
110	110 (4)_I-95 NB GP	4	4,268	Freeway Basic	Key calibration station DCP#6-9, DCP#72-75
111	111 (5)_I-95 NB GP	5	1,455	Freeway Diverge/Merge	Near IDR on-ramp; DCP#59-63
112	112 (4)_I-95 NB GP	4	1,200	Freeway Basic	Between IDR and HBB interchanges
113	113 (5)_I-95 NB GP	5	937	Freeway Basic	Near HBB diverge
114	114 (4)_I-95 NB GP	4	3,661	Freeway Basic	Northern terminus

2.3.2.2 SB GP Mainline

The I-95 SB GP facility (Table 26) is represented by 16 mainline freeway links (201–216), spanning from the Hallandale Beach Boulevard interchange in the north to the US 441/SR 9 area in the south. Lane counts range from 3 lanes (Links 207, 209, 211, 212, 214, 216) to 6 lanes (Link 205) at the widest section north of IDR. The southbound direction includes a notable 6-lane weave section (Link 205, 53.7 m) and a 5-lane weave section (Link 204, 459.9 m) that together represent the critical North-of-IDR weave zone, coded with a dedicated behavior type (BT 2014 — Freeway Weave N. of IDR). This zone is identified by the model team as a calibrated bottleneck, confirmed by the presence of time-windowed RSAs on adjacent links.

Table 26.SB GP Mainline Configuration

Link No.	Name	Lanes	Length (ft)	Behavior Type	Key Feature
201	201 (4)_I-95 SB GP	4	3,356	Freeway Basic	Northern entry; VI#201
202	202 (3)_I-95 SB GP	5	1,857	Freeway Basic	Name/lane count discrepancy
203	203 (4)_I-95 SB GP	4	398	Freeway Basic	Short transitional link
204	204 (5)_I-95 SB GP	5	1,509	Freeway Weave N.IDR	Key bottleneck
205	205 (6)_I-95 SB GP	6	176	Freeway Weave N.IDR	Widest section (6 lanes)
206	206 (4)_I-95 SB GP	4	20,614	Freeway Basic	Longest SB segment; DCP#1-4
207	207 (3)_I-95 SB GP	3	997	Freeway Basic	DCP#78-80
208	208 (4)_I-95 SB GP	4	1,108	Freeway Diverge/Merge	Near IDR interchange
209	209 (3)_I-95 SB GP	3	342	Freeway Basic	DCP#88-90
210	210 (4)_I-95 SB GP	4	676	Freeway Diverge/Merge	—

Table 26. SB GP Mainline Configuration (continued)

Link No.	Name	Lanes	Length (ft)	Behavior Type	Key Feature
211	211 (3)_I-95 SB GP	3	2,516	Freeway Basic	DCP#45-47, DCP#99-101
212	212 (3)_I-95 SB GP	3	738	Freeway Basic	DCP#21-23
213	213 (4)_I-95 SB GP	4	8,455	Freeway Aggressive Merge	Long aggressive merge zone south of IDR
214	214 (3)_I-95 SB GP	3	206	Freeway Basic	Short transition
215	215 (4)_I-95 SB GP	4	6,645	Freeway Basic	DCP#50-53
216	216 (3)_I-95 SB GP	3	1,265	Freeway Basic	Southern bottleneck

2.3.3 Express Lane / Managed Lane Configuration

The simulation model contains fully separated Express Lane (EL) facilities for both the northbound and southbound directions. The EL links are coded with distinct display types (DT=3000 and 3001) and dedicated driving behavior types (BT=2010 EL Basic; BT=2012 EL Merge/Diverge; BT=2013 EL Freeway Weave) that are calibrated independently from the GP driving behaviors. Separate vehicle compositions (Comp #3 — I-95 EL) and vehicle inputs (VI#301 NB EL; VI#401 SB EL) confirm that EL demand is modeled independently from GP demand.

2.3.3.1 NB Express Lane Links

The data presented in Table 27 reflect the modeled northbound express-lane corridor configuration.

Table 27. NB Express Lanes Configuration

Link No.	Name	Lanes	Length (ft)	Behavior Type	Key Feature
301	301 (1)_I-95 NB EL	1	6,482	EL Basic (2010)	Southernmost NB EL; DCP#55; VI#301
302	302 (2)_I-95 NB EL	2	4,014	EL Freeway Weave (2013)	2-lane EL weave section; DCP#29-30, 106-107
303	303 (1)_I-95 NB EL	1	16,108	EL Basic (2010)	Longest NB EL link; multiple DCP stations
304	304 (2)_I-95 NB EL	2	3,138	EL Merge/Diverge (2012)	EL access interaction zone

2.3.3.2 SB Express Lane Links

The data presented in Table 28 reflect the modeled southbound express-lane corridor configuration.

Table 28. SB Express Lanes Configuration

Link No.	Name	Lanes	Length (ft)	Behavior Type	Key Feature
401	401 (2)_I-95 SB EL	2	3,186	EL Basic (2010)	Northern SB EL; VI#401
402	402 (1)_I-95 SB EL	1	15,058	EL Basic (2010)	Longest SB EL link; DCP#5, 14, 38, 65, 77, 87
403	403 (2)_I-95 SB EL	2	5,613	Custom (BT 2016)	2-lane section; DCP#24-25, 48-49, 97-98, 108-109
404	404 (1)_I-95 SB EL	1	5,884	EL Basic (2010)	DCP#54

2.3.3.3 EL Access and Egress Summary

The data presented in Table 29 summarize the express-lane ingress and egress points.

Table 29. EL Access and Egress Points Configuration

Point	Direction	Ramp Link	Type	Length (ft)	Notes
AE-01	NB	Link 153	GP → EL (ingress)	463	1st NB EL access from GP; off-ramp from Link 103
AE-04	NB	Link 160	GP → EL (ingress)	469	2nd NB EL access from GP; separate diverge from Link 103 area
AE-03	NB	Link 156	EL → GP (egress)	164	NB EL to GP merge; very short
AE-06	SB	Link 255	GP → EL (ingress)	630	SB EL access; coded with EL behavior type (DT=3000)
AE-08	SB	Link 251	EL → GP (egress)	125	1st SB EL egress; very short merge
AE-09	SB	Link 258	EL → GP (egress)	203	2nd SB EL egress

2.3.4 Ramp and Arterial Configuration

2.3.4.1 NB Ramps

The data presented in Table 30 highlight that the NB off-ramp to IDR (Link 157, 1,919.9 ft) is the longest NB deceleration ramp, indicating a significant diverge taper length in this interchange.

Table 30. NB Ramps Configuration

Link No.	Name	Lanes	Length (ft)	BT	Type
151	I-95 NB On-Ramp from US441/SR9/NW7thAve	1	1,164	Freeway Basic	On-ramp (southern entry)
152	I-95 NB On-Ramp from NW2ndAve	1	1,071.8	Freeway Basic	On-ramp
153	I-95 NB Off-Ramp to EL	1	462.6	Freeway Basic	EL access diverge
154	I-95 NB Off-Ramp to MGD	1	647.3	Freeway Basic	MGD diverge; RSA#103
155	I-95 NB On-Ramp from MGD	1	329.7	Freeway Basic	MGD merge
156	I-95 NB On-Ramp from EL	1	165	Freeway Basic	EL egress merge
157	I-95 NB Off-Ramp to IDR	1	1,919.9	Freeway Basic	IDR diverge; long deceleration
158	I-95 NB On-Ramp from IDR	1	177.4	Freeway Aggressive Merge	IDR merge; short acceleration; critical
159	I-95 NB Off-Ramp to HBB	1	1,567.2	Freeway Basic	Northern terminal diverge
160	I-95 NB Off-Ramp to EL	1	143.2	Freeway Basic	Second EL access diverge

2.3.4.2 SB Ramps

The data presented in Table 31 highlight that the SB off-ramp to IDR (Link 253) is 2-lane — the only 2-lane SB off-ramp — indicating the high demand for IDR westbound movements. The SB off-ramp to EL (Link 255) is the only ramp coded with EL display and behavior types (DT=3000, BT=2010), distinguishing it as an EL-specific access link rather than a conventional GP off-ramp.

Table 31. SB Ramps Configuration

Link No.	Name	Lanes	Length (ft)	BT	Type
251	I-95 SB On-Ramp from EL	1	125	Freeway Basic	EL egress merge (very short)
252	I-95 SB On-Ramp from HBB	1	1,492.4	Freeway Basic	On-ramp (northern entry)
253	I-95 SB Off-Ramp to IDR	2	601	Freeway Basic	IDR diverge; widest off-ramp (2 lanes)
254	I-95 SB On-Ramp from IDR	1	481.9	Freeway Basic	IDR merge
255	I-95 SB Off-Ramp to EL	1	629.9	EL Basic (2010)	EL access diverge; EL-type coding
256	I-95 SB Off-Ramp to MGD	1	926	Freeway Basic	MGD diverge; anomalous length

Table 31. SB Ramps Configuration (continued)

Link No.	Name	Lanes	Length (ft)	BT	Type
257	I-95 SB On-Ramp from MGD	1	104.6	Freeway Basic	MGD merge (
258	I-95 SB On-Ramp from EL	1	203.4	Freeway Basic	Second EL egress merge
259	I-95 SB Off-Ramp to US441/SR9	2	576.7	Freeway Basic	Southern terminal diverge; 2 lanes; RSA#745-746

2.3.5 Interchanges

2.3.5.1 Miami Gardens Drive (MGD)

Miami Gardens Drive is represented in both the eastbound (EB, Links 501–564) and westbound (WB, Links 601–664) directions. The EB mainline includes a long through segment (Link 501, 3,644 m, 3 lanes) with short approach segments at the I-95 intersection (Links 502–505, 2–4 lanes). The WB mainline has a long through segment (Link 607, 3,393 m, 3 lanes) with approach widening at I-95 (Links 601–606, 2–3 lanes). Both directions include minor street approach links (NE 5th Ave, NE 6th Ave, NE 8th Ave) at cross-intersections. Signal control at the MGD/I-95 NB and SB intersections is provided by Ring-Barrier Controllers SC#203 and SC#204.

2.3.5.2 Ives Dairy Road (IDR) / NW 183rd Street

Ives Dairy Road is represented in both EB (Links 701–766) and WB (Links 801–860) directions. The IDR EB mainline includes a long through segment (Link 701, 7,606 m, 3 lanes) with a wide 5-lane approach at the I-95 intersection (Link 705) and a long eastern segment (Link 706, 9,417 m, 3 lanes). The IDR WB mainline includes long western and eastern segments (Links 807 and 801). Signal control at the IDR/I-95 SB, IDR/I-95 NB, and IDR/Highland Lakes Blvd intersections is provided by Ring-Barrier Controllers SC#103, SC#104, and SC#105 respectively. The IDR EB approach to I-95 NB (Links 853–856, BT=Freeway Aggressive Merge) is the key arterial-to-freeway merge zone for northbound I-95 traffic originating from IDR westbound. These links are coded with the same Aggressive Merge behavior type as NB ramp Link 158, indicating a short and potentially difficult merge condition.

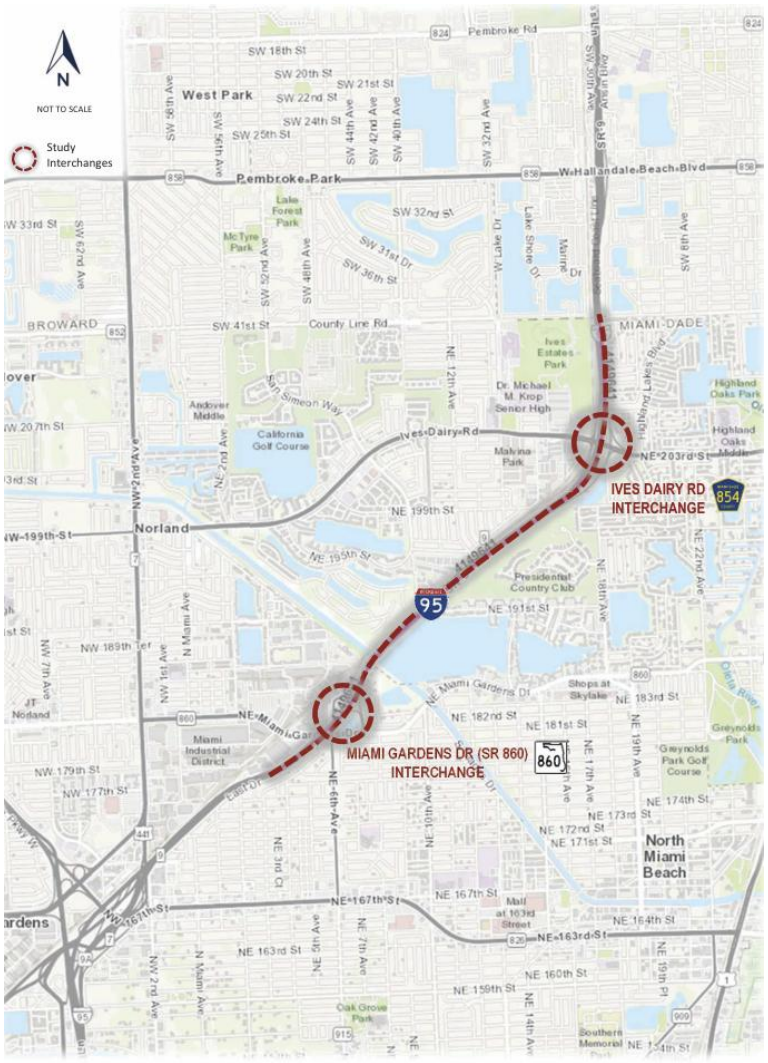


Figure 84. Project Location Map (Source: Florida Department of Transportation, 2021)

2.3.6 Traffic Control and Operational-Control Devices

2.3.6.1 Signalized Intersections

The model includes five Ring-Barrier signal controllers governing two at-grade intersections, as presented in Table 32. Also, a total of 58 signal heads and 27 signal groups are distributed across these controllers. Cycle length and phase timing information is defined in external signal program files as provided by Miami-Dade County.

Table 32. Signalized Intersections

Controller ID	Location	Intersection
SC#103	IDR SB	Ives Dairy Rd / I-95 SB ramp terminal
SC#104	IDR NB	Ives Dairy Rd / I-95 NB ramp terminal
SC#105	IDR HLB	Ives Dairy Rd / Highland Lakes Blvd
SC#203	MGD SB	Miami Gardens Dr / I-95 SB ramp terminal
SC#204	MGD NB	Miami Gardens Dr / I-95 NB ramp terminal

2.3.6.2 Priority Rules, Conflict Areas, and Stop Signs

13. 24 priority rules govern right-of-way at freeway ramp merge points and arterial intersection approaches. Key locations include IDR EB at I-95 (PR#17-19), IDR WB to I-95 SB (PR#20-21), IDR EB wide approach (PR#4 on Lane 5 of Link 705), and MGD EBL to I-95 NB (PR#8-9).
14. 177 conflict areas define vehicle path crossing zones at the IDR and MGD at-grade intersections, enabling realistic deceleration and yielding behavior.
15. 9 stop signs enforce yielding at minor turning movements at IDR and MGD intersections (e.g., SS#502 on NE 5th Ave NB Link 554; SS#702-807 on IDR/MGD connector links).

2.3.6.3 Data Collection and Performance Measurement Points

Table 33 lists the data collection and performance measurement points coded in the model.

Table 33. Data Collection and Performance Measurement Points

Object Type	Count	Primary Locations
Data Collection Points	110	NB GP (33); SB GP (23); NB EL (12); SB EL (15); other (27)
Travel Time Measurement Sections	22	SB corridor (TTM#1-16); NB corridor (TTM#17-22)
Signal Detectors	60	IDR and MGD intersection approaches and ramp terminals
Vehicle Routing Decisions	25	All major diverge points on GP and EL
Vehicle Routes	85	Defined paths from each routing decision

3 Simulation Platform Selection

The corridor model, adapted from the I-95/SR 9 PD&E study, was applied using PTV Vissim Version 2025, Service Package 06. Vissim is a microscopic traffic simulation platform, meaning that it represents traffic operations at the level of individual vehicles rather than only at the aggregate roadway-link level. Each vehicle in the model is assigned behavioral characteristics and interacts with surrounding vehicles based on car-following, lane-changing, gap-acceptance, merging, weaving, and queuing logic. This makes Vissim especially useful for evaluating freeway corridors where operational performance is strongly affected by lane-changing behavior, ramp merges/diverges, bottlenecks, managed-lane access points, and congestion spillback.

Unlike traditional planning models that rely primarily on a simplified link-node structure, Vissim uses a more detailed link/connector coding system. In this structure, roadway segments are represented by links, while connectors define how vehicles move from one link or lane group to another. This allows complex freeway geometry to be represented with high detail, including mainline lanes, express lanes, auxiliary lanes, ramps, weaving areas, tolling access points, pylons or buffer-separated facilities, intersections, and signalized or ramp-metered locations. Because traffic controls can be placed almost anywhere in the model, Vissim can represent a wide range of

operational strategies, such as signal control, ramp metering, variable speed limits, lane-use restrictions, transit priority, HOV/HOT lane rules, and managed-lane access control.

For demand representation, Vissim provides flexibility depending on the available data and study purpose. Under static routing, vehicle paths are predefined using turning-movement counts, detector volumes, or field-observed route proportions. This approach is commonly used when the analyst has reliable counts and wants vehicles to follow fixed routes through the network. Alternatively, Vissim can be used with Dynamic Traffic Assignment (DTA), where demand is entered as origin-destination matrices and vehicles are assigned routes based on generalized travel costs, such as travel time, distance, delay, or other route-choice assumptions. This makes DTA useful when the study needs to evaluate route shifts, managed-lane versus general-purpose-lane choices, or changes in travel behavior under different operational or pricing scenarios.

Vissim is particularly appropriate for managed lane, express lane, HOT lane, and HOV lane applications because it can model different vehicle classes, lane restrictions, tolling rules, occupancy eligibility, lane-changing behavior, and access/egress locations. This is important for express-lane corridors because the interaction between the managed lanes and adjacent general-purpose lanes is often influenced by driver behavior near ingress and egress points, weaving movements, speed differentials, and congestion levels. By simulating individual vehicles, Vissim can estimate detailed measures of effectiveness (MOEs) such as volume, speed, density, travel time, delay, queue length, throughput, lane utilization, bottleneck formation, and performance differences between express lanes and general-purpose lanes.

3.1 Insights from the literature

The use of Vissim for this type of study is also consistent with previous managed-lane and express-lane research. Prior microsimulation and hybrid modeling studies have been widely used to evaluate the operational, safety, and environmental performance of managed-lane and general-purpose-lane facilities. These studies show that microsimulation can capture how lane configuration, driver behavior, traffic control strategies, and access design affect mobility and safety outcomes. For instance, Ben-Akiva et al. (2003) developed one of the earliest microsimulation frameworks, known as *MITSIMLab*, which enables detailed evaluation of freeway traffic control strategies often paired with managed lanes. Their work established a foundational platform for modeling driver response, lane-changing dynamics, and control interventions under varying congestion and pricing conditions. Building upon such frameworks, Caltrans (2009) conducted a series of VISSIM-based analyses for managed lane corridors in Los Angeles and Orange County, focusing on HOT lane driver behavior calibration and access preference modeling. These efforts contributed standardized behavior parameters that can be directly applied to express and GP lane assessments.

A key advancement in linking operational and environmental models was introduced by Xu et al. (2016), who developed an automated interface between VISSIM and the U.S. EPA's MOVES model. This integration allows researchers to assess the emission impacts of operational changes

between express and general-purpose lanes, offering a framework for sustainability-focused evaluations. In a similar operational context, Sajjadi & Kondyli (2017) employed VISSIM to analyze SR-167 HOT lanes in Washington State and comparable segments in South Florida, focusing on capacity and speed–flow relationships under varying configurations of one-lane and two-lane facilities separated by flexible pylons. Abdel-Aty et al. (2020) used VISSIM to evaluate optimal Connected Vehicle (CV) lane configurations under varying market penetration rates and traffic conditions. The analysis incorporated safety (conflict frequency) and operational (speed, delay) metrics, identifying lane configuration strategies that improve both safety and mobility outcomes during peak and off-peak hours.

Guo et al. (2020) extended microsimulation research to mixed traffic and automated environments, assessing managed lane reliability and GP lane spillover effects using VISSIM. Their comparison of mixed-traffic, cooperative adaptive cruise control (CACC), and dedicated CACC lane scenarios demonstrated the system-level reliability improvements associated with automation-supportive ML designs. Similarly, Ma et al. (2021) applied VISSIM to evaluate Active Traffic Management (ATM) strategies, including Variable Speed Limits (VSL) and Ramp Metering (RM), on SR-408 in Orlando, Florida. The study showed that coordinated VSL–RM strategies significantly reduced crash risk and congestion propagation, underlining the effectiveness of co-deployed control mechanisms in expressway corridors with managed lanes. Expanding the operational dimension, Wei et al. (2023) evaluated contraflow HOV/managed lane designs along the I-215 corridor using VISSIM microsimulation. Results indicated that contraflow operations reduced average peak-hour delay by 76%, proving the operational benefits of reversible or directionally managed express facilities.

More recently, Naseri et al. (2024) utilized Aimsun microsimulation to analyze high-occupancy lane operations, offering before-and-after comparisons that revealed significant throughput gains and delay reductions on both managed and general-purpose lanes. Finally, Schönhofer et al. (2024) performed Aimsun-based feasibility and performance analyses of HOT lane scenarios, comparing lane choice, travel-time reliability, and environmental impacts relative to GP lanes. Their results support the use of integrated macroscopic–microscopic modeling frameworks for strategic evaluation of managed lane implementation. Table 34 summarizes these microsimulation-based studies.

Table 34. Microsimulation-Based Studies Evaluating Express and General-Purpose Lane Performance

Software	Authors (Year)	Study Context	Focus Area	Key Findings
MITSIMLab	Ben-Akiva et al. (2003)	Generic freeway corridor	Framework for microscopic evaluation of control strategies linked to managed lanes	Introduced a microsimulation platform capturing lane-changing and driver response; foundational for ML–GP integration modeling.
VISSIM	Caltrans (2014, 2019)	Los Angeles / Orange County corridors	HOT lane driver behavior calibration and access modeling	Developed behavioral calibration models and access preference parameters applicable to HOT–GP performance evaluation.
	Xu et al. (2016)	Expressway operational–environmental linkage (MOVES)	Integrated traffic–emission analysis	Automated VISSIM–MOVES linkage for evaluating emission changes due to operational improvements in ML vs. GP lanes.
	Sajjadi & Kondyli (2017)	SR-167 HOT (WA) & South Florida	ML–GP interactions, lane separation, and design	Found a 7.6% capacity drop for one-lane MLs with flexible pylons, stable flow in two-lane designs; informed speed–flow calibration.
	Abdel-Aty et al. (2020)	Controlled CV lane simulation	Connected Vehicle lane configuration (MPR sensitivity)	Evaluated safety (conflict frequency) and operational (speed, delay) metrics; identified optimal lane strategies by MPR.
	Guo et al. (2020)	Arterial and freeway ML networks	Managed lane reliability and CACC scenarios	Compared mixed, restricted, and dedicated CACC lanes; found improved stability and reliability under dedicated designs.
	Ma et al. (2021)	SR-408, Orlando (FL)	VSL + Ramp Metering (ATM) bundle analysis	Coordinated VSL–RM reduced congestion and crash risk; verified ATM as co-control for ML corridors.
	Wei et al. (2023)	I-215 corridor	Contraflow HOV/ML operations	Contraflow design reduced peak-hour delay by 76% vs. baseline; improved corridor throughput.
Aimsun	Naseri et al. (2024)	HOV → HOT/EL conversion	Before–after performance assessment	Documented significant throughput and delay reductions in both ML and GP lanes.
	Schönhofer et al. (2024)	HOT feasibility and performance analysis	Lane choice, travel-time reliability, environmental metrics	Found improved mode choice, reliability, and emission outcomes vs. GP baseline.

3.2 Simulation Software, Network Coding, and Automation

Another emerging parameter that should be considered when prioritizing simulation software is its ability to integrate with programming languages and support automation scripts. Although both Vissim and Aimsun provide automation and scripting capabilities, they differ in how they support external model control. This capability is particularly relevant for managed-lane studies, where various tolling and operational scenarios may need to be evaluated. Integration with programming languages can help automate toll changes, run multiple random seeds, modify demand inputs, extract speed and volume outputs, and test different express-lane control strategies more efficiently.

In Vissim, this is commonly done through the Component Object Model (COM) interface, which allows external scripts, including Python scripts, to communicate with the Vissim model. Through the COM interface, users can automate repetitive tasks such as changing vehicle inputs, adjusting routing decisions, modifying signal or toll-control logic, running multiple random seeds, and exporting measures of effectiveness. This capability is particularly useful for managed-lane applications where toll rates, lane-use rules, or operational strategies may need to be adjusted dynamically during the simulation. PTV maintains Vissim support resources specifically related to API/COM functionality, and its training materials include scripting in Vissim using the COM interface.

Aimsun also supports Python-based scripting and application programming interfaces. However, its scripting environment is more directly embedded within Aimsun Next, where Python scripts can be written and executed inside the software without the same external COM-based workflow commonly used in Vissim. Aimsun documentation describes Python scripting as an interpreted approach that can be executed directly within Aimsun Next, while its API can be used during microscopic or mesoscopic simulations to read and modify information related to vehicles, demand, control, and detector data.

Therefore, from a model-development perspective, Vissim's Python/COM interface is best understood as an automation and external-control layer, rather than as a separate simulation model. It allows the analyst to interact programmatically with the calibrated Vissim network, perform batch runs, implement customized control logic, and extract simulation outputs for calibration and scenario comparison. Aimsun provides similar automation and customization capabilities through its internal Python scripting and API framework. Both tools are therefore suitable for advanced managed-lane modeling, but the practical implementation workflow differs, as Vissim commonly relies on external COM-based automation, while Aimsun provides a more integrated Python scripting environment.

3.3 FDOT Practice and Software Continuity Considerations

Although both Vissim and Aimsun are widely used traffic simulation platforms, publicly available FDOT guidance and project scopes suggest that Vissim is more commonly referenced for project-level microsimulation analysis, particularly for freeway, interchange, corridor, and express-lane operational studies. FDOT scopes frequently refer to microsimulation tools such as SimTraffic, CORSIM, and/or Vissim, while recent traffic analysis reports from Districts 4 and 6 further indicate the continued prioritization of Vissim for detailed corridor-level operational evaluations. At the same time, Aimsun has also been applied in FDOT-related contexts, particularly for regional integrated corridor management and predictive decision-support applications, such as the Central Florida Regional Integrated Corridor Management System, where Aimsun Live was used as the predictive engine.

Therefore, the selection of Vissim for this study is consistent with FDOT's established practice for detailed corridor-level microsimulation and express-lane evaluation, while Aimsun remains a relevant platform for regional, mesoscopic, and real-time operational applications. This continuity is an important consideration because, although Aimsun may be able to import or interpret certain Vissim network files in some cases, transitions between different Vissim versions are generally smoother and more practical. This can be especially beneficial for studies conducted within similar geographic regions or along previously modeled corridors, where existing Vissim network files can be updated, refined, and reused to save time and resources while supporting different operational evaluation objectives.

4 VISSIM Model Inputs and Calibration Checks

This section describes the input data and the checks applied to the VISSIM model for existing conditions. The model was inherited from the I-95/SR 9 PD&E study and adapted by the Research Team for this deliverable. The model inputs and the checks described below follow current FDOT guidance, including the 2025 FDOT Traffic Analysis Handbook, accepted microsimulation practices, and sound engineering judgment.

4.1 Existing Traffic Volumes

For the I-95 mainline study segment, 72-hour bi-directional vehicle volume and speed data were obtained from RITIS for three separate weekday periods. The data were collected in 15-minute intervals for the following dates:

1. July 22–24, 2025
2. August 12–14, 2025
3. September 16–18, 2025

These datasets were reviewed to identify a representative day for use in the Vissim calibration process. Each candidate day was compared against the multi-day median traffic profile and evaluated using several statistical measures. The purpose of this screening process was to select a typical weekday that reflected recurring traffic conditions while avoiding days that appeared to be affected by incidents, detector errors, or unusual traffic patterns.

Each candidate day was scored using the following metrics:

1. Pearson correlation, to evaluate similarity in the shape of the 15-minute traffic profile;
2. Mean Absolute Percentage Error (MAPE), to measure the average percentage difference from the median profile;
3. Symmetric Mean Absolute Percentage Error (SMAPE), to provide a balanced percentage error measure;
4. Normalized Root Mean Square Error (nRMSE), expressed as a percentage of the median mean volume;
5. Robust z-score of total daily volume, to identify unusually high or low daily volume totals relative to the sample median;
6. Robust z-scores of AM and PM peak-period volumes, to evaluate whether peak-period traffic volumes were typical compared with the other candidate days.

In addition to the volume-based consistency checks, a speed-based anomaly and incident screening procedure was performed. The analysis used the volume-weighted speed data from RITIS. For each 15-minute interval, the speed observed on a candidate day was compared with the median speed for the same interval across the full multi-day dataset. Intervals were flagged as potentially anomalous when the observed speed fell more than 1.5 times the interquartile range (IQR) below the lower quartile. These flagged intervals were reviewed as potential indicators of incidents, abnormal congestion, or detector-related issues.

The number of flagged intervals for each day was incorporated into the composite scoring process. Candidate days with high profile similarity, low error measures, typical daily and peak-period volumes, and fewer speed anomalies were considered more representative for Vissim calibration. This process ensured that the selected calibration day reflected typical operating conditions along the I-95 corridor rather than conditions influenced by isolated incidents or abnormal traffic behavior.

4.1.1 Corridor-Level Volume Profiles

Figure 85 presents the 24-hour corridor-level 15-minute volume profiles for all nine candidate days. The profiles show a clear recurring weekday pattern, with traffic volumes increasing sharply during the early morning period, remaining elevated through much of the daytime, and gradually declining during the evening and overnight hours. The recommended representative day, September 17, 2025, closely follows the typical corridor profile during both the AM and PM analysis periods, without showing major disruptions or abnormal volume drops. The backup day, August 13, 2025, also follows a generally consistent pattern and was therefore retained as a suitable alternative.

It is important to note that the three Tuesday datasets show visibly lower total corridor volumes. This reduction is not interpreted as a true traffic pattern, but rather as a data availability issue associated with missing SB-GP Link201 data. Therefore, these days were not considered as strong candidates for representative-day selection, even if portions of their profiles appeared reasonable.

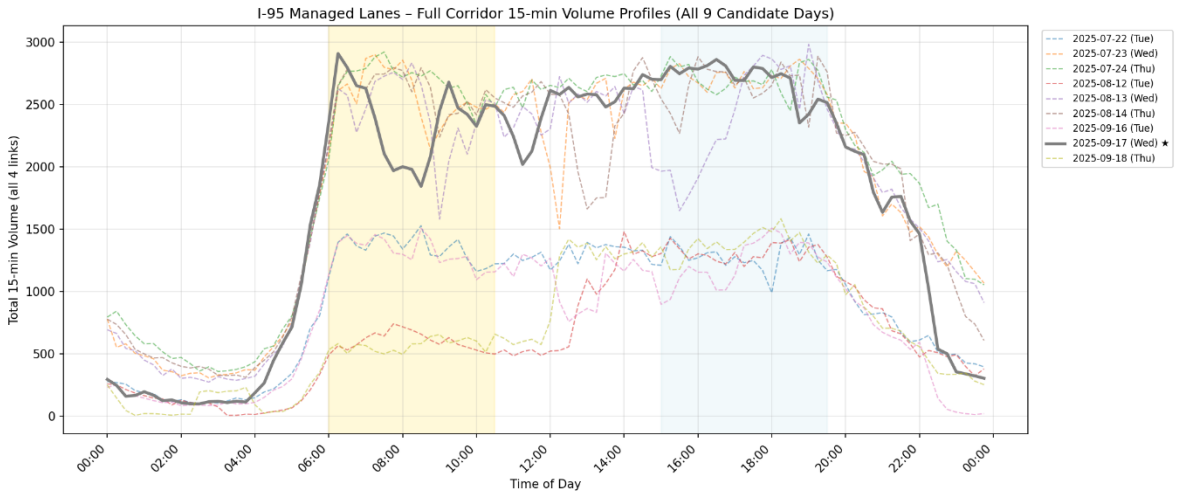


Figure 85. 15-minute Corridor Volume Profiles for All Candidate Days

Figure 86 presents the same 15-minute volume profiles separated by direction. This directional comparison provides a clearer view of how northbound and southbound traffic patterns vary throughout the day. The northbound profile shows a more pronounced morning increase, while the southbound profile carries higher sustained volumes during much of the daytime and afternoon period. The September 17 profile remains generally consistent with the typical directional patterns and does not show the severe missing-data behavior observed in the Tuesday datasets.

The directional plots also confirm that the unusually low corridor totals on Tuesdays are primarily caused by missing or incomplete southbound GP data rather than an actual reduction in traffic demand. This supports the decision to exclude those days from final representative-day consideration and reinforces September 17, 2025, as the preferred calibration day.

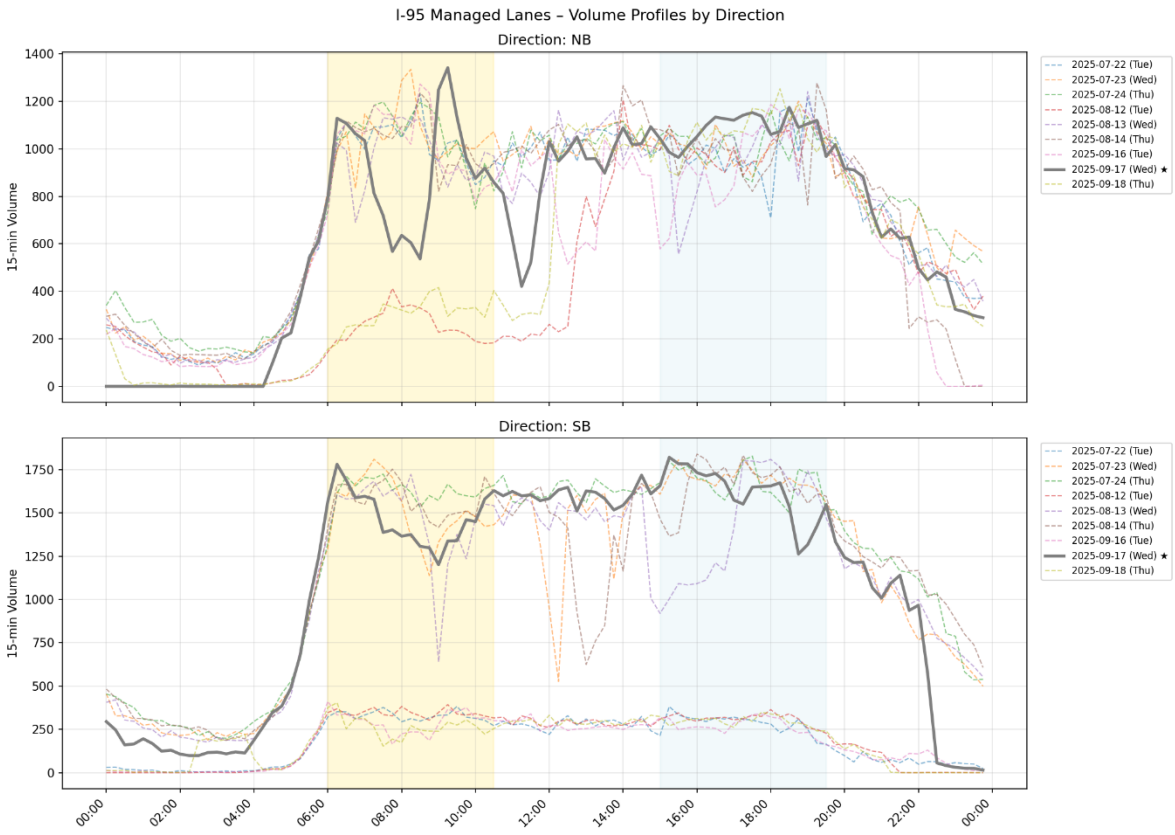


Figure 86. 15-minute Volume Profiles by Direction

4.1.2 Speed Profiles by Link

Figure 87 presents the volume-weighted speed profiles for each analyzed link over the 24-hour period. These profiles were reviewed to determine whether the candidate days reflected typical recurring traffic conditions or whether any day appeared to be affected by an incident, detector issue, or unusual congestion pattern. Overall, the speed profiles show consistent daily operating patterns across most candidate days. Free-flow speeds are generally observed during the overnight and early morning periods, followed by noticeable speed reductions during the AM peak and, for some links, during the PM peak. This pattern is expected along a heavily traveled managed-lanes corridor and indicates recurring congestion rather than isolated abnormal conditions.

The general-purpose lane links show moderate speed reductions during peak periods, while the express-lane links exhibit more pronounced speed variability at certain times of day. This is especially visible on the southbound express-lane link, where recurring speed drops occur during both the AM and PM periods. However, these reductions are not persistent throughout the entire day, which suggests that they are related to peak-period congestion rather than a full-day incident or detector failure.

September 17, 2025, remains a strong representative-day candidate because its speed profile follows the typical congestion pattern observed across the other valid candidate days. Although localized speed drops are present, they occur during expected congested periods and recover afterward. The day does not show an abnormal all-day speed collapse, extended zero-speed condition, or corridor-wide disruption that would indicate a major incident-affected day.

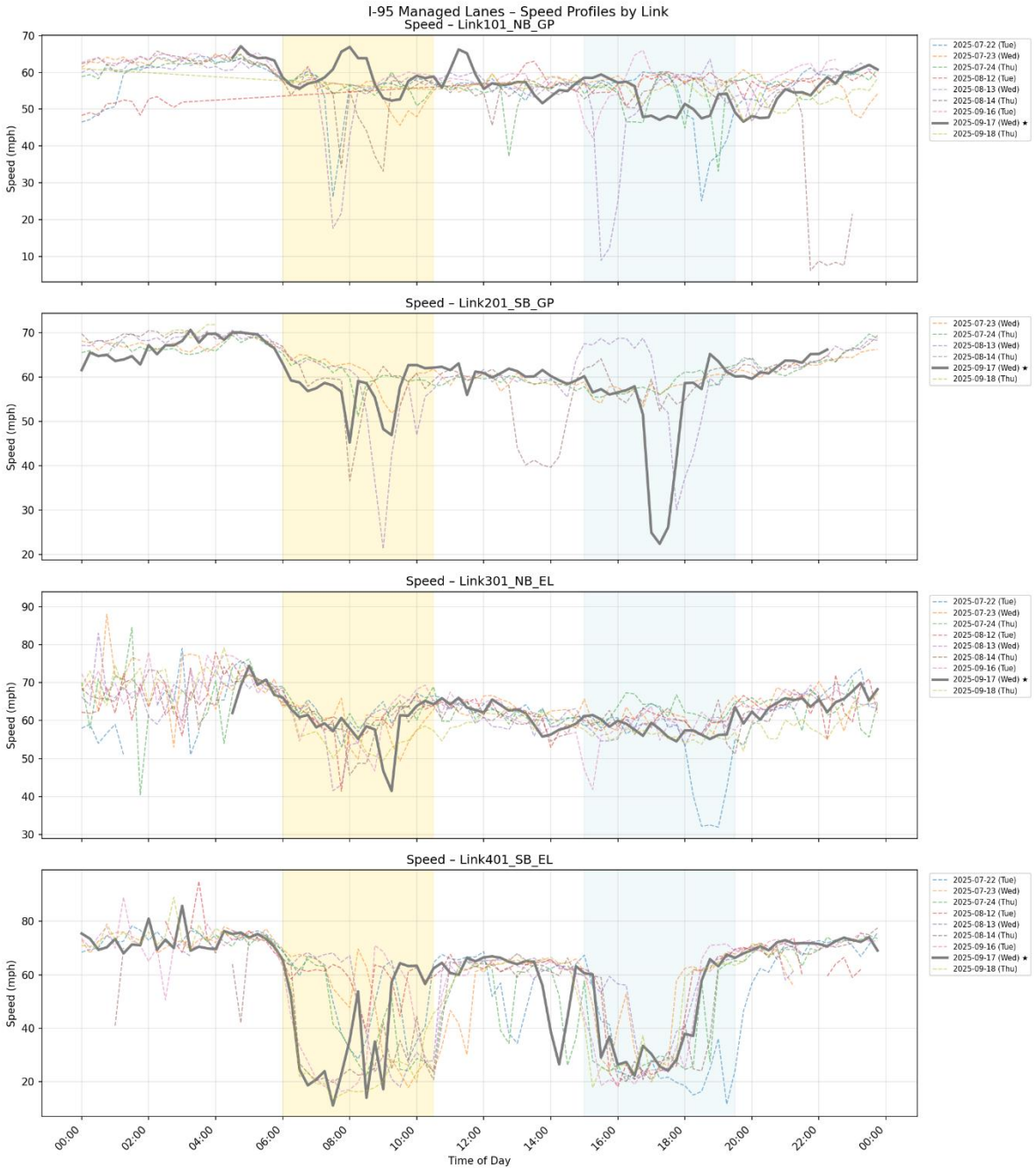


Figure 87. Volume-Weighted Speed Profiles by Link

4.1.2.1 Per-Link Profile Comparisons vs Median

Figure 88 through **Figure 91** present the per-link 15-minute volume and speed profiles for the four instrumented I-95 managed-lane segments. Each figure compares the candidate days against the multi-day median profile, with the recommended representative day and backup day highlighted for review. These link-level comparisons were used to confirm that the selected day is representative not only at the overall corridor level, but also at the individual segment and lane-group level.

More specifically, the per-link profiles highlight that September 17, 2025 generally follows the multi-day median pattern across the northbound general-purpose lanes, southbound general-purpose lanes, northbound express lanes, and southbound express lanes. The selected day captures the expected morning build-up, sustained daytime traffic levels, and evening decline without showing an abnormal full-day disruption. This consistency supports its use as the representative calibration day. In addition, the link-level plots help identify localized differences that may be hidden in the corridor-level totals. For example, the general-purpose lane profiles show higher sustained volumes during the daytime period, while the express-lane profiles show lower volumes but more noticeable speed sensitivity during congested periods. The southbound express lane segment exhibits the most pronounced recurring speed reductions, which is consistent with peak-period managed-lane congestion rather than an isolated incident.

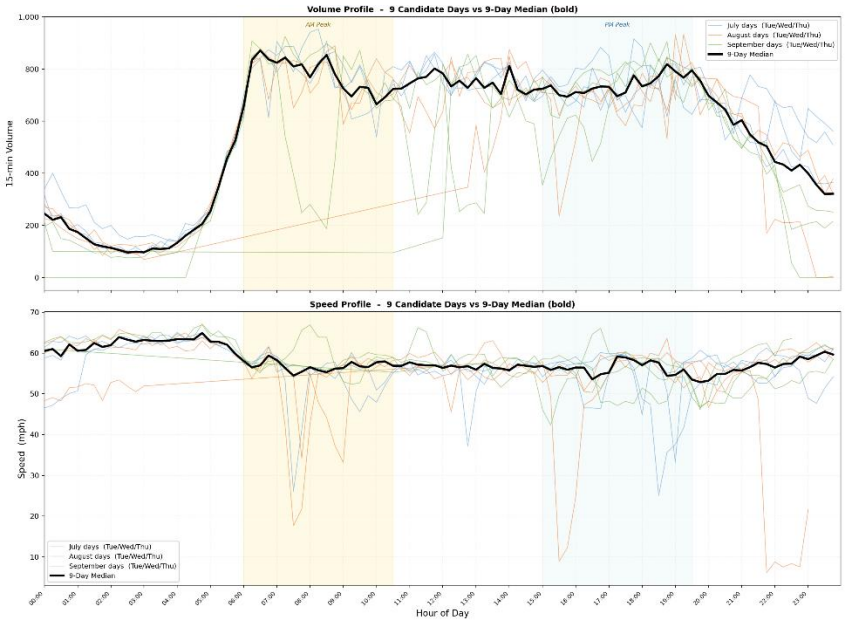


Figure 88. Link 101, Northbound General-Purpose Lanes: 15-Minute Volume and Speed Profiles versus Multi-Day Median

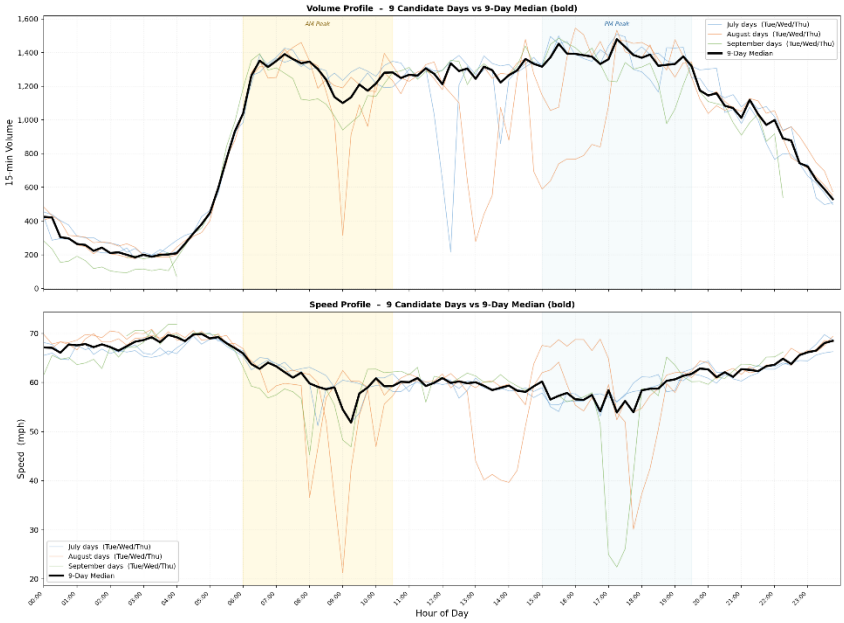


Figure 89. Link 201, Southbound General-Purpose Lanes: 15-Minute Volume and Speed Profiles versus Multi-Day Median

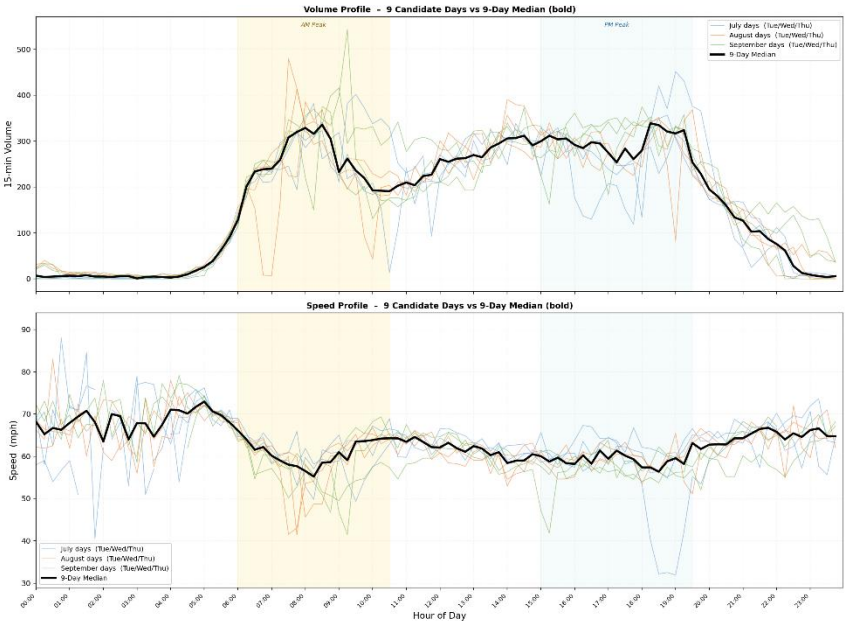


Figure 90. Link 301, Northbound Express Lanes: 15-Minute Volume and Speed Profiles versus Multi-Day Median

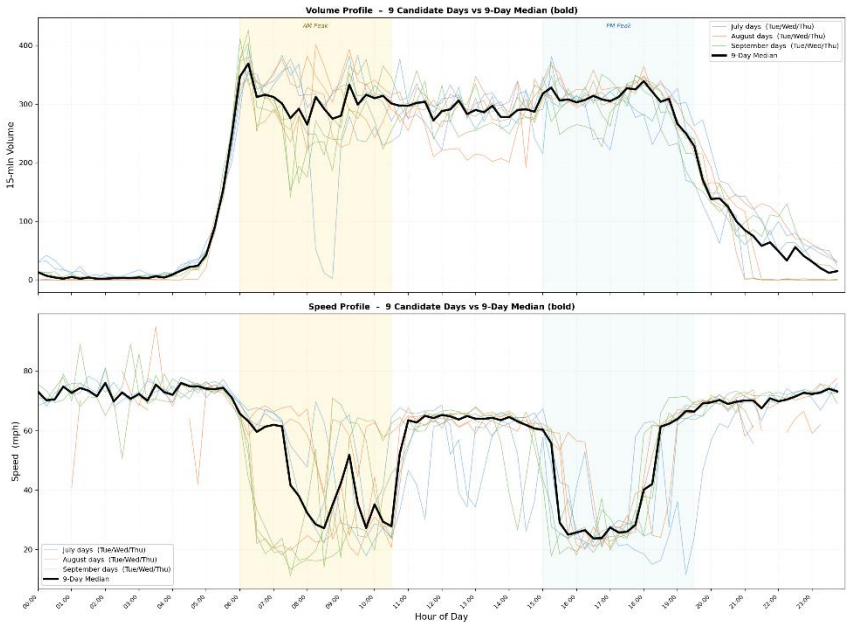


Figure 91. Link 401, Southbound Express Lanes: 15-Minute Volume and Speed Profiles versus Multi-Day Median

4.1.2.2 Incident and Anomaly Screening

Speed-based anomaly screening was performed to identify candidate days that may have been affected by non-recurring congestion, incidents, unusual weather, detector errors, or other abnormal operating conditions. The screening was applied across the four analyzed links using the volume-weighted speed profiles. For each 15-minute interval, the observed speed on each candidate day was compared against the multi-day speed distribution for the same interval. Intervals were flagged as potentially anomalous when the observed speed fell more than 1.5 interquartile ranges below the lower quartile of the multi-day speed distribution.

Figure 92 presents the corridor-level speed profiles for all candidate days compared with the multi-day median. The figure shows that September 17, 2025, the recommended representative day, follows the general median speed pattern throughout the day. Speed reductions are visible during the AM and PM peak periods, but these reductions occur during expected congested periods and recover afterward. Therefore, they are more consistent with recurring bottleneck congestion than with an isolated incident or detector malfunction. More specifically, some candidate days showed patterns that were less suitable for calibration. September 18 and August 12 had low anomaly counts, but those results were influenced by degraded data completeness, meaning the low number of flags likely reflected missing data rather than truly stable traffic conditions. August 14 had the highest anomaly count, with 28 flagged intervals, and its speed profile shows an extended low-speed period not observed on the other candidate days. This suggests a possible incident, maintenance activity, or other non-recurring condition, which contributed to its lower composite ranking despite otherwise acceptable volume completeness.

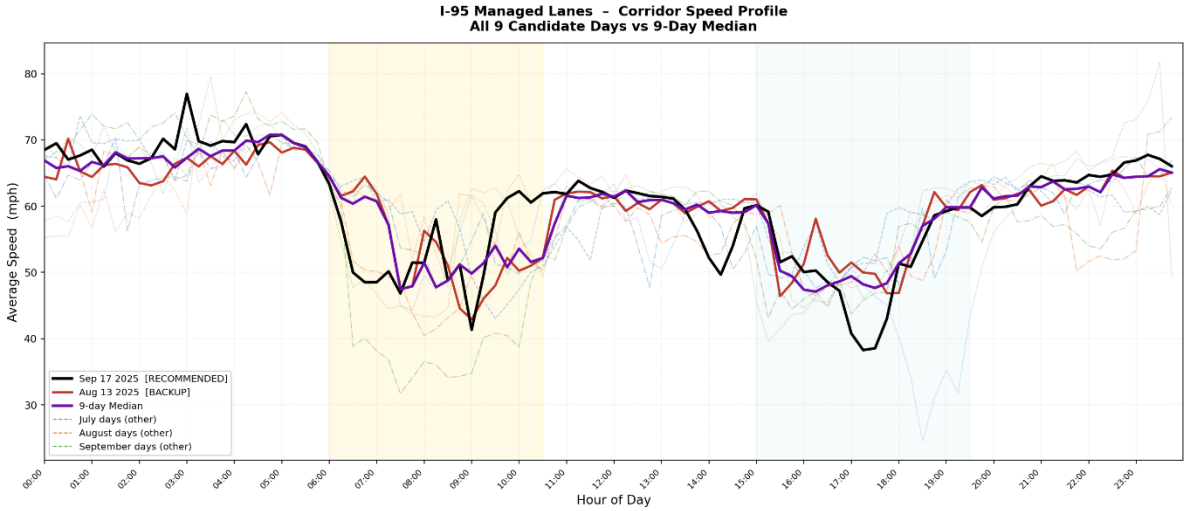


Figure 92. Corridor-Level Speed Profiles versus Multi-Day Median

4.1.2.3 Recommended Representative Day

Based on the multi-day screening analysis, Wednesday, September 17, 2025 was selected as the recommended representative day for Vissim calibration. Table 35 summarizes the key statistical measures supporting this selection. The results indicate that September 17 closely follows the typical corridor traffic pattern, has high detector completeness, and does not show evidence of a non-recurring incident or abnormal all-day disruption.

Table 35. Recommended Day Summary Statistics

Metric	Value — September 17, 2025
Correlation with Median	0.9580
MAPE vs Median	15.15%
Normalized RMSE	22.67%
Robust Z-score — Daily Total	0.000 (≈ 0 = median-typical)
Robust Z-score — AM Peak	0.000
Robust Z-score — PM Peak	0.647
Average Detector Completeness	98.5%
Incident Anomaly Flags	14
Daily Corridor Volume	169,956 vehicles
AM Peak Volume (6:00–10:30)	42,579 vehicles
PM Peak Volume (15:00–19:30)	48,798 vehicles
Peak Hour Volume	11,271 vehicles
Average All-day Speed	59.9 mph

The selected day achieved the highest composite score of 0.9445 and ranked highest across most of the individual evaluation metrics. Its correlation with the multi-day median profile was 0.9580, indicating strong agreement with the typical 15-minute traffic pattern observed across the candidate days. In addition, the day had the lowest MAPE, 15.15%, showing that its interval-by-interval volume profile was closest to the median corridor behavior. The robust z-scores provide additional support for the selection. September 17 had robust z-scores of 0.000 for both the daily total volume and AM peak volume, meaning these values were essentially median-typical within

the sample. The PM peak z-score of 0.647 also remained within a reasonable range, indicating that the PM volume was not an extreme outlier.

Data completeness was also high, with an average detector completeness of 98.5%. Only two intervals were missing on Link101, and the missing data did not materially affect the overall profile. The day recorded 14 speed anomaly flags, but these occurred during expected AM and PM peak-period congestion windows rather than as an extended all-day speed collapse. Therefore, the flagged intervals were interpreted as recurring congestion rather than evidence of a non-recurring incident. From an operational perspective, the daily corridor volume of 169,956 vehicles, AM peak volume of 42,579 vehicles, PM peak volume of 48,798 vehicles, and average all-day speed of 59.9 mph are consistent with a typical weekday operating condition. Because the selected day was a mid-week Wednesday within the September analysis window and was not close to a major holiday or transition period, it provides a stable and defensible basis for developing Vissim input volumes and calibration targets.

4.2 Vissim Model Input

4.2.1 Vehicle Models and Distributions

Following the materials provided in the I-95 District 6 PD&E study, the North America Vehicle Models and Distributions developed by PTV America were adopted in this study. For passenger vehicles, PTV America selected representative vehicle models and corresponding distributions based on North American vehicle sales data. The resulting passenger vehicle model distribution is presented in Table 36.

Table 36. Car Models and Distribution (source: PTV America)

Make	Model	Type	Percentage	3D Vehicle Model
Ford	F-150	Truck	19.2%	LTruck_Ford_F150_2009
Chevrolet	Silverado	Truck	15.1%	LTruck_Chevrolet_Silverado_2008
Toyota	Avensis	Car	13.5%	Car_Toyota_Avensis_2006
Ford	Explorer	SUV	10.6%	SUV_Ford_Explorer_2008
Honda	Accord	Car	12.9%	Car_Honda_Accord_2003
Plymouth	Voyager	Truck	5.5%	Van_Plymouth_Voyager_1999
Jeep	Grand Cherokee	SUV	5.8%	SUV_Jeep_Grand_Cherokee_2002
Nissan	Quest	Car	6.4%	Van_Nissan_Quest_1995
GMC	Yukon	SUV	5%	SUV_GMC_Yukon_XL_2008
Nissan	Altima	Car	6%	Car_Nissan_Altima_2005

In addition, because freight mobility is an important component of this study, the representation of heavy vehicles was given particular attention. PTV America selected the Heavy Goods Vehicle (HGV) models and distributions based on a truck size and weight study. The resulting truck model distribution is presented in Table 37.

Table 37. Truck Models and Distribution (source: PTV America)

Truck Type	Percentage	Tractor	Trailer
5-Axle Tractor Semi-trailer	48.0%	HGV_wb50_tractor.v3d	HGV_wb50_trailer.v3d
3-Axle Single Unit Truck	27.5%	HGV-EU04 Tractor	
4-Axle Tractor Semi-trailer	10.5%	HGV_wb40_tractor.v3d	HGV_wb40_trailer.v3d
4-Axle or more Single Unit Truck	5%	HGV_flatbed_truck.v3d	
3-Axle Tractor Semi-trailer	4.5%	HGV_wb67d_tractor.v3d	HGV_wb67d_trailer.v3d
6-Axle Tractor Semi-trailer	4.5%	HGV_wb65_tractor.v3d	HGV_wb65_trailer.v3d

4.2.2 Speed Distributions

Following the materials provided in the I-95 District 6 PD&E study, desired speed distributions were developed based on the posted speed limits observed in the field. The posted speed limits used in the model are summarized earlier in this report. A key modeling assumption adopted from the I-95 District 6 PD&E study was that drivers on the express lanes in Miami-Dade County typically travel above the posted speed limit. Based on observed field conditions, desired speeds on the express lanes in the Vissim model were increased by 5 mph to better reflect actual operating speeds. The desired speed distributions used in the model are shown in Table 38.

Table 38. Speeds Distribution

Facility or Function Type	Posted Speed (mph)	Lower Limit	15% Percentile	85% Percentile	Upper Limit
Freeway Mainline (GP and EL)	65	60	65	70	75
Freeway Mainline (GP and EL)	60	55	60	65	70
Arterials	40	35	40	45	50
Arterials	35	30	35	40	45
Arterials	30	25	30	35	40
Arterials	25	20	25	30	35
School Zone*	15	14	14.5	15	18
Left Turn Movement*	n/a	12	15	18	21
Right Turn Movement*	n/a	8	10	12.5	15
Free or Channelized Right Turn*	n/a	15	20	22.5	25

For the general speed distributions, the 85th percentile speed was assumed to be 5 mph higher than the posted speed limit. The upper limit of the speed distribution was set at 10 mph above the posted speed limit, while the lower limit was set at 5 mph below the posted speed limit. The upper speed range represents free-flow operating conditions. Trucks were modeled with desired speeds 5 mph lower than passenger cars. Reduced speed areas were also coded in the Vissim model to reflect lower-speed operating conditions at specific locations. Loop ramps were modeled using reduced speed areas based on their design speeds. For interchange ramps, the segment closest to the

freeway mainline was modeled using the corresponding mainline speed. Additional reduced speed distributions were developed for left-turn movements, right-turn movements, and free-flow or channelized right-turn movements. Furthermore, reduced speed areas were included to reflect the 15 mph school zone speed limit along Ives Dairy Road and to represent congested segments outside the immediate study area. These congested segments include southbound I-95 north of the Golden Glades Interchange (GGI) and portions of Ives Dairy Road east and west of the interchange in both the eastbound and westbound directions.

4.2.3 Traffic Composition

Following the materials provided in the I-95 District 6 PD&E study, the Design Hour Truck (DHT) values used in this study were based on historical data from FDOT count stations within the study area, mechanical classification counts, and turning movement counts collected by the Department as part of the project data collection effort.

Table 39. Truck Percentages

Road	T Peak Hour
I-95 General-Use Lanes	3
I-95 Express Lanes	0
Miami Gardens Drive	2
Ives Dairy Road	2

The DHT values from the mechanical classification counts were calculated as one-half of the daily truck percentage, consistent with the FDOT Project Traffic Forecasting Handbook. Based on the existing and historical traffic data, a DHT value of 3% was used for I-95, while a DHT value of 2% was used for Miami Gardens Drive and Ives Dairy Road. These truck percentages were applied to define the traffic composition in the Vissim model. The resulting vehicle composition, including the percentage of passenger cars and trucks at the model entry links, is summarized in Table 39.

4.2.4 Vehicle Inputs

Based on the traffic analysis, the identified AM and PM peak-hour conditions, and the methodology used in the I-95 District 6 PD&E study, a four-hour analysis period was adopted for the Vissim simulations. In addition, a 30-minute seeding period was included at the beginning of each simulation to allow vehicles to populate the network before the evaluation period begins.

The four-hour analysis period provides sufficient time to capture the development of congestion, peak-period operations, and the subsequent dissipation of congestion. This approach allows the model to better represent traffic conditions before, during, and after the peak hour. The Link 101 counter site on SR 9A/I-95 near Pembroke Road in the southbound direction was selected as the representative location for developing the 15-minute vehicle input distribution. The synopsis report from this counter site was used to distribute traffic volumes across the simulation period in 15-minute intervals. Table 40 presents the resulting 15-minute vehicle distribution factors for the

full 4.5-hour simulation horizon, including the 30-minute seeding period and the four-hour analysis period, for both the AM and PM peak-period scenarios.

Table 40. Peak Period Vehicle Input Distributions

Interval	AM Time Interval	Hourly Proportion	15min Distribution	PM Time Interval	Hourly Proportion	15min Distribution
1	6:15 AM–6:30 AM	74.1%	26.5%	4:00 PM–4:15 PM	89.3%	25.3%
2	6:30 AM–6:45 AM		33.7%	3:15 PM–4:30 PM		25.2%
3	6:45 AM–7:00 AM	100%	25.8%	4:30 PM–4:45 PM	91.6%	25.1%
4	7:00 AM–7:15 AM		24.8%	4:45 PM–5:00 PM		25.4%
5	7:15 AM–7:30 AM		24.4%	5:00 PM–5:15 PM		25.4%
6	7:30 AM–7:45 AM		25.0%	5:15 PM–5:30 PM		24.1%
7	7:45 AM–8:00 AM	95.2%	25.3%	5:30 PM–5:45 PM	94.1%	23.9%
8	8:00 AM–8:15 AM		25.4%	5:45 PM–6:00 PM		26.1%
9	8:15 AM–8:30 AM		23.9%	6:00 PM–6:15 PM		24.7%
10	8:30 AM–8:45 AM		25.4%	6:15 PM–6:30 PM		25.1%
11	8:45 AM–9:00 AM	90.4%	27.9%	6:30 PM–6:45 PM	100%	24.5%
12	9:00 AM–9:15 AM		25.5%	6:45 PM–7:00 PM		26.0%
13	9:15 AM–9:30 AM		23.8%	7:00 PM–7:15 PM		25.1%
14	9:30 AM–9:45 AM		22.7%	7:15 PM–7:30 PM		24.4%
15	9:45 AM–10:00 AM	83.3%	25.9%	7:30 PM–7:45 PM	92.7%	27.2%
16	10:00 AM–10:15 AM		25.8%	7:45 PM–8:00 PM		25.8%
17	10:15 AM–10:30 AM		23.7%	8:00 PM–8:15 PM		23.9%
18	10:30 AM–10:45 AM		24.6%	8:15 PM–8:30 PM		23.1%

4.2.5 Other Input Variables

Following the methodology adopted in the I-95 District 6 PD&E study, static vehicle routes were coded in the Vissim model. The “Combine Routes” option was selected to provide drivers with sufficient distance and time to position themselves in the correct lane before reaching their intended downstream movement.

Static routing decisions were also used for the express-lane facilities. This approach was appropriate because express-lane demand was treated as fixed, and alternative toll-pricing strategies were not evaluated as part of this analysis. In addition, modeling dynamic express-lane choice would require accounting for travel-time savings outside the study area. The express-lane routes were coded to allow passenger cars only.

The freeway mainline entry links were extended to more than 1.5 miles, and arterial entry links were extended to more than 0.5 mile. These extensions provided sufficient distance for lane-changing maneuvers and helped ensure that all coded traffic demand could enter the network without being artificially constrained at the model boundaries.

Stop signs and signal heads were coded in the model to reflect field conditions. Signal timings were coded consistent with the signal timing plans obtained from Miami-Dade County. Conflict areas were coded for movements with potential conflicts, such as right-turn movements conflicting with through movements and permitted left-turn movements conflicting with opposing through traffic. Priority rules were also included where needed to prevent queues from unrealistically blocking intersections.

4.3 Vissim Model Calibration

Following standard microsimulation practice, the model's ability to replicate observed traffic-flow patterns was assessed by comparing simulated traffic volumes and speeds with observed data.

4.3.1 Calibration Criteria

The FDOT calibration criteria, including those in the FDOT Traffic Analysis Handbook, were used as the reference targets for these comparisons and are summarized in Table 41.

Table 41. Freeway Model Calibration Criteria

Criteria and Measures	Calibration Acceptance Targets
Hourly Flows, Model Versus Observed	
Individual Link Flows	
Within 100 veh/h, for Flow < 700 veh/h	> 85% of cases
Within 15%, for 700 veh/h < Flow < 2700 veh/h	> 85% of cases
Within 400 veh/h, for Flow > 2700 veh/h	> 85% of cases
Sum of All Link Flows	Within 5% of sum of all link counts
GEH Statistic < 5 for Individual Link Flows	> 85% of cases
GEH Statistic for Sum of All Link Flows	GEH < 5 for sum of all link counts
Speed	Modeled average link speeds to be within ±10 mph of field-measured speeds on at least 85% of all network links.
Visual Audits	Check consistency with field conditions of the following: on- and off-ramp queuing; weaving maneuvers; patterns and extent of queue at intersections and congested links; lane utilization/choice; location of bottlenecks.

For traffic-volume calibration, modeled link flows were compared with observed field counts. In addition to direct volume-difference thresholds, the Geoffrey E. Havers (GEH) statistic was used to evaluate the similarity between modeled and observed volumes across a range of traffic conditions. The GEH statistic is useful because it provides a balanced comparison for both low-volume and high-volume links.

The GEH statistic is calculated as follows:

$$GEH = \sqrt{\frac{2(M-C)^2}{M+C}}$$

where:

1. M= modeled or simulated traffic volume
2. C= observed traffic count

Model speeds were also compared with field-measured speeds, with the objective of achieving average link speeds within the accepted FDOT tolerance. In addition, a visual audit of the model was performed to verify that simulated traffic operations were consistent with field conditions.

This visual review included observations of:

1. on-ramp and off-ramp queuing,
2. weaving maneuvers,
3. queue patterns and queue extents at intersections and congested links,
4. lane utilization and lane choice,
5. bottleneck locations.

A detailed quantitative comparison of modeled and observed queues was not performed; such a comparison is not typically required unless specifically requested by the Department or dictated by the project requirements.

4.3.2 Number of Simulation Runs

Following standard microsimulation procedures, the existing-conditions reference models were simulated using ten (10) runs with different random seeds (42 to 87 in increments of 5). A simulation resolution of 10 time steps per simulation second was applied to provide detailed vehicle movement and lane-changing behavior. The model was also reviewed for coding errors and compared with observed traffic volume and speed data obtained from the RITIS database. The incident scenarios were evaluated with two paired random seeds (42 and 47), as described in the Comparison Methodology section of the incident analysis.

4.3.3 Calibration Metrics

The results presented in Table 42 and Table 43 summarize the peak-hour volume comparison for the SR 9/I-95 roadway segments as tabulated for the model, with GEH values below 5 for all listed segments. Therefore, the volume calibration results are in full compliance with FDOT calibration criteria.

Table 42. AM Peak Hour Volume Calibration Results for SR 9/I-95 Roadway Segments

Facility	Direction	Segment	% Served	GEH < 5	Acceptance Target
I - 9	I - 9	South of Miami Gardens Drive to EL Ingress Point	99%	0.2 / Yes	Yes < 400

Facility	Direction	Segment	% Served	GEH < 5	Acceptance Target
		From EL Ingress Point to Miami Gardens Drive Off-ramp	100%	0.1 / Yes	Yes < 400
		Between Miami Gardens Drive Interchange	100%	0.4 / Yes	Yes < 400
		From Miami Gardens Drive On-Ramp to EL Egress Point	98%	1.1 / Yes	Yes < 400
		From EL Egress Point to Ives Dairy Road Off-Ramp	98%	0.6 / Yes	Yes < 400
		From Ives Dairy Road Off-Ramp to On-Ramp	99%	1.1 / Yes	Yes < 400
		North of Ives Dairy Road	93%	3.4 / Yes	Yes < 400
		North of Ives Dairy Road	100%	0.1 / Yes	Yes < 400
	I-95 SB	Between Ives Dairy Road Ramps	100%	0.2 / Yes	Yes < 400
		From Ives Dairy Road On-Ramp to EL Ingress Point	99%	0.3 / Yes	Yes < 400
		From EL Ingress Point to Miami Gardens Drive Off-Ramp	100%	0 / Yes	Yes < 400
		Between Miami Gardens Drive Ramps	98%	0.5 / Yes	Yes < 400
		South of Miami Gardens Drive to EL Egress Point	99%	0.5 / Yes	Yes < 400
		From Egress Point to South	99%	0.3 / Yes	Yes < 400

Table 42. AM Peak Hour Volume Calibration Results for SR 9/I-95 Roadway Segments (continued)

Facility	Direction	Segment	% Served	GEH < 5	Acceptance Target
I-95 Express Lanes	I-95 NB	South of Miami Gardens Drive to Ingress Point	100%	0 / Yes	Yes < 15%
		From Ingress Point to Ives Dairy Road Egress Point	99%	0.2 / Yes	Yes < 15%
		From Ives Dairy Road Egress Point to Ives Dairy Road Ingress Point	100%	0.1 / Yes	Yes < 15%
		From Ives Dairy Road Ingress Point to North	99%	0.2 / Yes	Yes < 15%
	I-95 SB	North to Ives Dairy Road Egress Point	100%	0.1 / Yes	Yes < 15%
		From Ives Dairy Road Egress Point to Ives Dairy Road Ingress Point	100%	0.1 / Yes	Yes < 15%
		From Ives Dairy Road Ingress Point to Egress Point	98%	0.6 / Yes	Yes < 15%
		From Egress Point to South	100%	0 / Yes	Yes < 15%

Table 43. PM Peak Hour Volume Calibration Results for SR 9/I-95 Roadway Segments

Facility	Direction	Segment	% Served	GEH < 5	Acceptance Target
I-95 General-Use Lanes	I-95 NB	South of Miami Gardens Drive to EL Ingress Point	100%	0.1 / Yes	Yes < 400
		From EL Ingress Point to Miami Gardens Drive Off-ramp	99%	0.1 / Yes	Yes < 400
		Between Miami Gardens Drive Interchange	100%	0.1 / Yes	Yes < 400
		From Miami Gardens Drive On-Ramp to EL Egress Point	97%	1.1 / Yes	Yes < 400
		From EL Egress Point to Ives Dairy Road Off-Ramp	97%	0.8 / Yes	Yes < 400
		From Ives Dairy Road Off-Ramp to On-Ramp	98%	1.9 / Yes	Yes < 400
		North of Ives Dairy Road	96%	1.9 / Yes	Yes < 400
		North of Ives Dairy Road	98%	0.1 / Yes	Yes < 400
	I-95 SB	Between Ives Dairy Road Ramps	98%	0.6 / Yes	Yes < 400
		From Ives Dairy Road On-Ramp to EL Ingress Point	98%	1.3 / Yes	Yes < 400
		From EL Ingress Point to Miami Gardens Drive Off-Ramp	100%	0.2 / Yes	Yes < 400
		Between Miami Gardens Drive Ramps	99%	0.3 / Yes	Yes < 400
		South of Miami Gardens Drive to EL Egress Point	98%	0.5 / Yes	Yes < 400
		From Egress Point to South	98%	0.3 / Yes	Yes < 400
I-95 Express Lanes	I-95 NB	South of Miami Gardens Drive to Ingress Point	100%	0.1 / Yes	Yes < 15%
		From Ingress Point to Ives Dairy Road Egress Point	99%	0.1 / Yes	Yes < 15%
		From Ives Dairy Road Egress Point to Ives Dairy Road Ingress Point	100%	0.5 / Yes	Yes < 15%
		From Ives Dairy Road Ingress Point to North	100%	0.1 / Yes	Yes < 15%
	I-95 SB	North to Ives Dairy Road Egress Point	100%	0.1 / Yes	Yes < 15%
		From Ives Dairy Road Egress Point to Ives Dairy Road Ingress Point	99%	0.1 / Yes	Yes < 15%
		From Ives Dairy Road Ingress Point to Egress Point	99%	0.2 / Yes	Yes < 15%
		From Egress Point to South	99%	1.2 / Yes	Yes < 15%

Table 44. AM and PM: Speed Calibration Parameters - Southbound

Loc.	Time	General Use Lanes — RITIS	General Use Lanes — Vissim	Express Lanes — RITIS	Express Lanes — Vissim
1	AM	57	69	43	64
	PM	44	65	47	55
2	AM	47	55	59	57
	PM	46	52	60	59
3	AM	51	56	56	53
	PM	50	55	65	54
4a	AM	52	55	47	44
	PM	51	55	64	61
4b	AM	47	55	37	42
	PM	53	55	66	61
5	AM	52	55	35	40
	PM	56	55	65	59
6	AM	55	54	33	60
	PM	53	54	62	59

Table 45. AM and PM: Speed Calibration Parameters - Northbound

Loc.	Time	General Use Lanes — RITIS	General Use Lanes — Vissim	Express Lanes — RITIS	Express Lanes — Vissim
1	AM	66	67	70	64
	PM	62	66	65	65
2	AM	64	52	72	60
	PM	60	54	65	59
3	AM	63	58	72	61
	PM	61	55	66	59
4a	AM	60	58	71	65
	PM	60	55	65	63
4b	AM	56	57	70	65
	PM	58	54	64	61
5	AM	56	53	61	60
	PM	55	53	60	55
6	AM	53	54	64	58
	PM	48	52	59	57

For clarification, and consistent with the methodology used in the I-95 District 6 PD&E study, the following data collection locations were used for the spot-speed calibration:

1. Location 1: Between SR 858/Hallandale Beach Boulevard and CR 854/Ives Dairy Road, including the express-lane ingress/egress area
2. Location 2: Between CR 854/Ives Dairy Road and the express-lane ingress/egress area
3. Location 3: Between CR 854/Ives Dairy Road and SR 860/Miami Gardens Drive, and between express-lane ingress/egress points
4. Location 4a: Between the express-lane ingress/egress area and Miami Gardens Drive
5. Location 4b: Between the express-lane ingress/egress area and SR 860/Miami Gardens Drive
6. Location 5: Between the SR 860/Miami Gardens Drive ramps
7. Location 6: Between SR 860/Miami Gardens Drive and the Golden Glades Interchange

Table 44 and Table 45 list 56 spot-speed comparisons (seven locations, AM and PM, general-use and express lanes), of which 48 (85.7%) are within the FDOT tolerance of ±10 mph, meeting the 85% target as tabulated.

5 Incident Scenarios Operational Impact Analysis

The incident scenario analysis was developed to evaluate how different types and severities of non-recurring disruptions affect traffic operations within the modeled I-95 managed-lanes corridor. Each scenario was coded as a separate VISSIM network alternative using time-windowed Reduced Speed Areas to represent temporary operational impacts such as shoulder-side slowdowns, lane obstructions, adjacent-lane friction, ramp disruptions, express-lane incidents, rubbernecking, and long-duration events. The scenarios differ by facility type, direction, number of affected lanes, incident duration, and severity of speed reduction. By design, SC-01 and SC-08 represent minor events (a shoulder-side slowdown and rubbernecking only); SC-02, SC-02B, SC-04, SC-05 and SC-06 represent localized disruptions on GP lanes, express lanes, ramps, or access/egress areas; and SC-03 and SC-07 represent multi-lane near-blockages with adjacent-lane friction. These design categories describe the scenario inputs, not the resulting impacts, which are reported in the following sections. Because the scenarios are implemented through reduced-speed treatments, they should be interpreted as incident-impact approximations rather than confirmed full lane closures. Lane 1 denotes the rightmost lane; the link, lanes, location and active period of every scenario are listed in Appendix U (Table 132).

5.1 Incident Scenario Descriptions

5.1.1 SC-01: Minor Shoulder-Side Incident

SC-01 represents a minor shoulder-side incident on the northbound general-purpose lanes. This could represent a disabled vehicle, police activity, or a minor crash located near the right shoulder.

The scenario does not block a full travel lane. Instead, it applies a reduced-speed condition to the rightmost GP lane to represent driver caution and rubbernecking near the shoulder.

5.1.2 SC-02: One GP Lane Near-Blockage

SC-02 represents a one-lane obstruction on the northbound general-purpose lanes. A very low speed of 3 mph is applied to one lane, making that lane operate almost like a blocked lane. However, because vehicles may still enter and pass through the lane, this scenario should be interpreted as a near-blockage, not a confirmed full lane closure.

5.1.3 SC-02B: One GP Lane Near-Blockage with Adjacent-Lane Friction

SC-02B is an improved version of SC-02. It keeps the 3 mph near-blockage on the rightmost GP lane and adds a reduced-speed area on the adjacent lane. This represents the turbulence caused by vehicles merging away from the incident lane and drivers slowing down next to the incident.

5.1.4 SC-03: Two GP Lanes Near-Blocked

SC-03 represents a more severe incident affecting the two right-side northbound GP lanes (link 109). Both affected lanes are assigned a 3 mph reduced-speed condition over 200 ft, while the next adjacent lane is assigned a rubbernecking/friction speed distribution (8 to 18 mph in the AM model and 5 to 15 mph in the PM model) over 300 ft, from 3,000 to 5,400 seconds of the simulation. This scenario approximates a crash or disabled-vehicle event that significantly reduces GP capacity.

5.1.5 SC-04: One Express Lane Near-Blockage

SC-04 represents an incident within the northbound Express Lane facility. A 3 mph reduced-speed condition is applied to one Express Lane. This scenario tests how an incident inside the managed-lane facility affects express-lane operations and potentially the interaction between Express Lanes and GP lanes.

5.1.6 SC-05: Ramp Merge Incident

SC-05 represents a disruption on a ramp or ramp-merge area. A 15 mph reduced-speed condition is applied to the affected ramp lane. This could represent a disabled vehicle, minor crash, or operational disturbance near a merge point. The goal is to evaluate whether a ramp incident affects mainline flow and merge operations.

5.1.7 SC-06: Incident Near Express Lane Access Point

SC-06 represents an incident near an Express Lane access or egress area. The rightmost GP lane is treated as severely obstructed, and the adjacent lane is assigned a reduced-speed friction condition. This scenario is designed to test the sensitivity of the GP/Express Lane interface, where lane-changing, weaving, and access movements may already be operationally complex.

5.1.8 SC-07: Long-Duration Severe Incident

SC-07 represents the longest and most extensive incident in the set. It is coded on the southbound GP facility (link 204) and is active from 2,700 to 9,000 seconds, significantly longer than the other scenarios. Two GP lanes are assigned 3 mph near-blockage speeds, and an adjacent lane receives a rubbernecking/friction speed distribution (8 to 18 mph AM; 5 to 15 mph PM). This scenario is intended as a stress test to evaluate corridor resilience, queue growth, recovery time, and potential network-wide impacts under a major incident.

5.1.9 SC-08: Rubbernecking Only

SC-08 represents a non-blocking rubbernecking event on the southbound GP facility (link 216). No lane is obstructed; the rightmost lane is assigned a rubbernecking speed distribution (8 to 18 mph AM; 5 to 15 mph PM) over approximately 490 ft, from 6,200 to 7,800 seconds in the AM model and from 7,500 to 9,000 seconds in the PM model.

5.2 Comparison Methodology

Each incident scenario was simulated for the full peak period (16,200 seconds, comprising a 30-minute seeding period and a four-hour analysis period) with two random seeds, 42 and 47. Each incident run is compared with a no-incident reference run that uses the same random seed and the same VISSIM version, and the two paired differences are then summarized by their values, mean and range. This paired design isolates the effect of the incident from differences between random seeds. Values therefore differ from those in the Deliverable 3 report as originally submitted; Appendix U (Table 135) summarizes the differences.

In the AM peak, the reference runs are the existing-conditions model runs with 10 random seeds (VISSIM 2025). The PM incident scenarios were run in VISSIM 2025, whereas the archived PM existing-conditions runs were produced with VISSIM 2023; because a change of software version alone shifts network delay by an amount comparable to small incident effects, PM incident effects are measured against a same-version no-incident reference, a VISSIM 2025 PM run identical to the incident files except that no incident is active, with 10 random seeds. Re-simulating this PM reference reproduced the archived reference results exactly, confirming that the comparison is not affected by the execution environment.

Two delay measures are reported. The full-run effect is the change in total in-network delay (vehicle-hours, veh-h) averaged over the four hourly evaluation intervals between 1,800 and 16,200 seconds and expressed in veh-h per interval; this is the network-wide measure used throughout this Part. The incident-window effect is the change in total in-network delay summed over the first two evaluation intervals (1,800 to 9,000 seconds), which contain every incident and its immediate recovery. Because traffic conditions in the later intervals can diverge between the incident and reference runs, the incident-window effect is the more direct indicator of an incident's own impact; the two measures are reported separately and are not combined. Delay experienced

by vehicles that could not enter the network (latent or unserved demand) is reported separately from in-network delay.

Scenario effects are grouped qualitatively using the incident-window change on both seeds: severe (at least about 400 veh-h on both seeds), clear/moderate (at least 50 veh-h on both seeds), small (10 to 50 veh-h on both seeds, same sign), negligible (below 10 veh-h), and uncertain (mixed sign). These thresholds are descriptive groupings, not statistical tests.

Because two paired random seeds were available for most incident scenarios, the results are interpreted primarily as scenario-based sensitivity findings rather than precise estimates of population-average effects. Identical runs reproduce exactly in VISSIM, so differences between the ten seeds reflect random-seed sensitivity across stochastic realizations of traffic, not run-to-run variability of a single simulation. Results that are consistent and large on both paired seeds are treated as robust; where the two seeds differ substantially in magnitude, the uncertainty is stated.

5.3 Network-Wide Incident Effects

Table 46 summarizes the paired network-wide effects of the AM peak incident scenarios. SC07 produced by far the largest impact, increasing in-network delay by +556.2 and +503.0 veh-h per interval on the ten seeds (mean +529.6 veh-h per interval, +62.3%) and by +544.0 and +421.0 veh-h over the incident window, while reducing average network speed by about 6.0 mph. SC03 produced a clear and consistent effect (+105.5 and +70.9 veh-h per interval; +201.1 and +174.1 veh-h over the incident window). SC05 produced a positive incident effect in both paired runs, but the magnitude was seed-sensitive (+149.2 and +36.2 veh-h per interval; +223.3 and +77.8 veh-h over the incident window), so its magnitude relative to SC03 cannot be ranked with confidence. SC06 increased delay by +183.2 and +99.8 veh-h during the incident window, but recovery after the incident largely offset this increase over the full run (−18.1 and +33.6 veh-h per interval; mean about +8). SC01 and SC02B produced small effects (incident window +32.7 and +24.9 veh-h, and +26.5 and +40.8 veh-h), while SC02, SC04 and SC08 had negligible network-wide effects under the tested conditions (mean full-run changes of +1.4, +0.1 and 0.0 veh-h per interval).

Table 46. AM Peak — Network-Wide Paired Incident Effects

Scenario	Incident (lanes affected)	Delay Δ, (veh-h per interval)	Delay Δ, mean (veh-h per interval)	Delay Δ (%)	Incident-window Δ, (veh-h)	Effect group
SC07	SB GP: 2 lanes near-blocked + 1 slowed (2,700-9,000 s)	+556.18 / +503.04	+529.61	+62.3%	+544.00 / +420.99	Severe
SC03	NB GP: 2 lanes near-blocked + 1 slowed	+105.50 / +70.93	+88.22	+10.4%	+201.11 / +174.10	Clear / moderate
SC05	NB on-ramp merge (1 lane)	+149.20 / +36.17	+92.68	+10.9%	+223.34 / +77.78	Clear / moderate; seed-sensitive magnitude
SC06	NB GP near EL access: 1 lane blocked + 1 slowed	−18.08 / +33.57	+7.75	+0.9%	+183.19 / +99.76	Moderate in incident window; small net effect
SC01	NB GP: shoulder-side lane slowed	+13.83 / +21.62	+17.72	+2.1%	+32.66 / +24.94	Small
SC02B	NB GP: 1 lane near-blocked + adjacent friction	+6.62 / +10.20	+8.41	+1.0%	+26.48 / +40.82	Small
SC02	NB GP: 1 lane near-blocked	+1.13 / +1.61	+1.37	+0.2%	+4.52 / +6.44	Negligible
SC04	NB EL: 1 lane near-blocked	+0.10 / +0.10	+0.10	0.0%	+0.41 / +0.41	Negligible
SC08	SB GP: rubbernecking only	+0.17 / −0.16	0.00	0.0%	+0.69 / −0.65	Negligible

Note: Delay Δ is the change in total in-network delay relative to a no-incident reference run with the same random seed and VISSIM version, in veh-h per hourly interval (mean of four intervals, 1,800 to 16,200 seconds); the percentage is relative to the reference. Incident-window Δ is the change summed over 1,800 to 9,000 seconds. Effect groups are based on the incident-window change on both seeds (see Comparison Methodology). Seed-by-seed values for additional measures are given in Appendix U.

Results presented in Table 47 summarize the paired, same-version network-wide effects of the PM peak incident scenarios. SC07 was again by far the most disruptive scenario, increasing in-network delay by +347.6 and +462.6 veh-h per interval on the ten seeds (mean +405.1 veh-h per interval, +42.0%) and by +727.9 and +819.1 veh-h over the incident window, while reducing average network speed by about 5.0 mph. The corrected SC03 two-lane near-blockage produced a clear effect on both seeds: +159.94 and +349.72 veh-h over the incident window (mean +254.83 veh-h) and +44.15 and +82.07 veh-h per interval over the full run (mean +63.11 veh-h per interval). During the incident itself the two seeds agree closely; the larger seed value reflects a secondary breakdown downstream of the incident location after the incident cleared.

SC06 produced a meaningful incident-window increase (+117.8 and +86.6 veh-h), but recovery after the incident offset it over the full run (+53.4 and −27.5 veh-h per interval; mean +12.9). SC05 had a small incident-window effect (+12.6 and +16.8 veh-h). SC02, SC04 and SC08 had negligible network-wide effects (mean full-run changes of +1.2, +0.1 and +0.4 veh-h per interval). SC01 showed no clear incident-window effect (+0.3 and −20.0 veh-h) and a lower full-run delay than the reference (−40.9 and −40.2 veh-h per interval) that arises later in the analysis period rather than during the incident; it is not interpreted as a beneficial incident effect. Usable simulation output was not available for SC02B in the PM peak, so no PM result is reported for that scenario.

Table 47. PM Peak — Network-Wide Paired Incident Effects (Same-Version Reference)

Scenario	Incident (lanes affected)	Delay Δ, (veh-h per interval)	Delay Δ, mean (veh-h per interval)	Delay Δ (%)	Incident-window Δ, (veh-h)	Effect group
SC07	SB GP: 2 lanes near-blocked + 1 slowed (2,700-9,000 s)	+347.60 / +462.58	+405.09	+42.0%	+727.93 / +819.10	Severe
SC03	NB GP: 2 lanes near-blocked + 1 slowed	+44.15 / +82.07	+63.11	+6.5%	+159.94 / +349.72	Clear / moderate
SC06	NB GP near EL access: 1 lane blocked + 1 slowed	+53.38 / −27.49	+12.94	+1.3%	+117.75 / +86.59	Moderate in incident window; small net effect
SC05	NB on-ramp merge (1 lane)	+3.16 / −21.05	−8.95	−0.9%	+12.63 / +16.82	Small (incident window)
SC01	NB GP: shoulder-side lane slowed	−40.93 / −40.16	−40.54	−4.2%	+0.29 / −19.97	Uncertain (no clear incident effect)
SC02	NB GP: 1 lane near-blocked	+1.13 / +1.37	+1.25	+0.1%	+4.50 / +5.49	Negligible
SC04	NB EL: 1 lane near-blocked	+0.09 / +0.07	+0.08	0.0%	+0.37 / +0.28	Negligible
SC08	SB GP: rubbernecking only	+0.43 / +0.47	+0.45	0.0%	+1.64 / +1.76	Negligible
SC02B	NB GP: 1 lane near-blocked + adjacent friction	-	-	-	-	No usable output

Note: As for Table 46. The PM reference is a same-version (VISSIM 2025) no-incident run with the same seed. SC03 reflects the corrected scenario configuration (Appendix U, Section U.6). Usable simulation output was not available for PM SC02B.

5.4 Latent (Unserved) Demand in the Most Severe Scenario

In-network delay counts only vehicles that entered the simulated network. When an incident causes queues to reach the network boundary, additional vehicles wait outside the network, and VISSIM records their waiting time as latent delay. For SC07, latent delay increased substantially and consistently on both seeds, so in-network delay alone understates the scenario's system impact

(Appendix U, Table 130). Combining the in-network delay change with the latent-delay change gives a derived expanded system impact of approximately 1,030 veh-h per interval in the AM peak and 1,519 veh-h per interval in the PM peak, about twice and nearly four times the in-network effect, respectively. These expanded values are derived measures incorporating VISSIM latent-delay information; they are not native VISSIM network-delay outputs, and the native in-network delay values in Tables 46 and 47 remain the primary network-wide measure. In the other scenarios, latent-delay changes were much smaller (below about 70 veh-h per interval in magnitude) and often differed in sign between seeds; for the corrected PM SC03, latent delay was essentially unchanged during the incident.

5.5 Incident Effects by Hourly Interval

Results presented in **Figure 93** show the paired change in network delay in each hourly evaluation interval for the three AM scenarios with the largest incident-window effects; bars show the two seeds and the line their mean. For SC07, the delay increase grows through the analysis period on both seeds, from 138 to 157 veh-h in the first hour to 850 to 1,010 veh-h in the fourth hour, indicating that the long-duration incident creates queues that accumulate and persist well after the incident ends at 9,000 seconds.

SC03 increases delay by 73 to 115 veh-h in each of the first three hours on both seeds, a consistent effect that remains well below that of SC07. SC05 also increases delay in each of the first three hours on both seeds, but the size differs markedly between seeds (for example, 189 versus 38 veh-h in the second hour), illustrating the seed sensitivity of this scenario's magnitude.

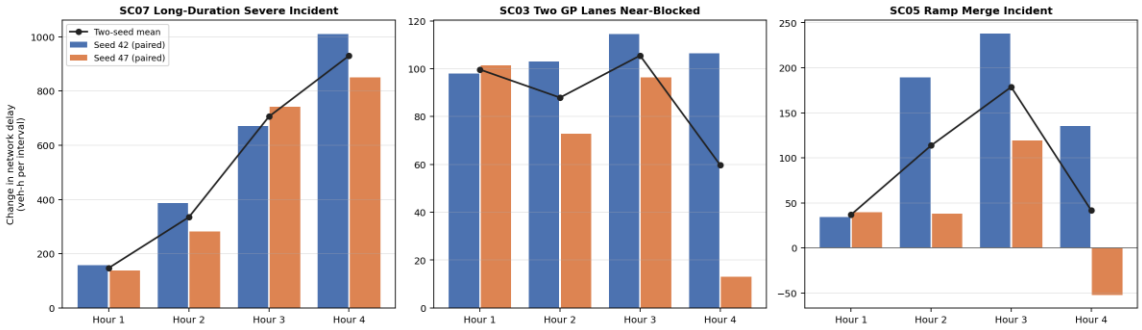


Figure 93. AM Peak — Per-Interval Paired Change in Network Delay: SC07, SC03 and SC05

Results presented in **Figure 94** show the corresponding PM paired changes for SC07, the corrected SC03 and SC06. SC07 adds 241 and 300 veh-h in the first hour and between 487 and 519 veh-h in each of the second and third hours on both seeds; in the fourth hour the increase is 175 and 521 veh-h, showing that the effect persists after the incident ends but with a seed-dependent tail.

The corrected SC03 adds 117 and 159 veh-h in the first hour, which contains the whole incident. On the larger seed, a secondary breakdown downstream of the incident location after the incident clears adds a further 191 and 88 veh-h in the second and third hours, compared with 43 and 5 veh-h on the smaller seed. SC06 increases delay mainly in the second hour (109 and 80 veh-h); later differences are of opposite sign between the seeds (for example, +104 and −141 veh-h in the fourth hour), which is why its full-run net effect is small and uncertain.

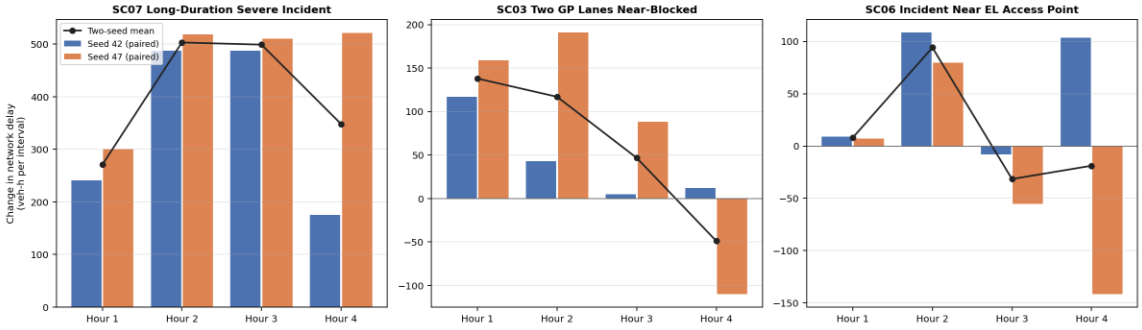


Figure 94. PM Peak — Per-Interval Paired Change in Network Delay: SC07, SC03 and SC06

5.6 Speed Effects by Lane Group and Vehicle Class

Figure 95 shows the paired change in average speed by lane group and vehicle class, measured at the corridor data-collection points (positive values are speed reductions; values are two-seed means). In the AM peak, SC07 reduces general-purpose lane speeds by 3.4% for cars and 4.1% for HGVs, while express-lane speeds are slightly higher than in the reference run (−1.5% for cars), consistent with the incident being located in the GP lanes. SC03 and SC05 produce smaller changes, and SC02 and SC02B, shown separately, have almost no effect at these detectors.

For the PM peak, as shown in **Figure 96**, speed changes at the detectors are generally smaller. SC07 again shows the largest general-purpose lane reductions (0.4% for cars and 1.0% for HGVs), and the corrected SC03 reduces general-purpose lane speeds by 0.8% for cars and 1.2% for HGVs. Most other values are close to zero, indicating that the localized incidents had limited corridor-wide speed effects at the detector locations.

Positive values represent speed reductions, while negative values indicate speeds slightly higher than in the paired reference run. Small negative values reflect flow redistribution or the limited sensitivity of corridor-wide detector averages and should not be interpreted as operational improvements caused by an incident. Express-lane HGV values rest on very small HGV samples (about 1% of vehicles counted at the express-lane detectors) and are not interpreted.



Figure 95. AM Peak: Paired Speed Reduction (%) by Lane Group and Vehicle Class

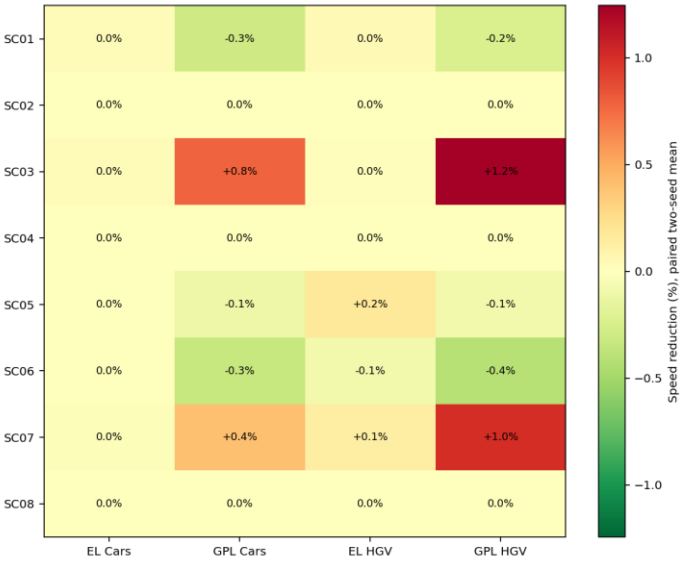


Figure 96. PM Peak: Paired Speed Reduction (%) by Lane Group and Vehicle Class

5.7 Passenger-Vehicle and HGV Impacts

Figure 97 compares the paired change in average delay per vehicle for passenger vehicles (cars) and HGVs; bars show the ten-seed mean and whiskers the seed values. In the AM peak, SC07 increases average delay per vehicle by about 63% for cars and 99% for HGVs, and SC03 by about 10% and 12%; in both scenarios the HGV increase exceeds the car increase on both seeds. SC05 shows similar relative increases for both classes, with the seed sensitivity noted earlier, and the remaining scenarios show small or negligible changes.

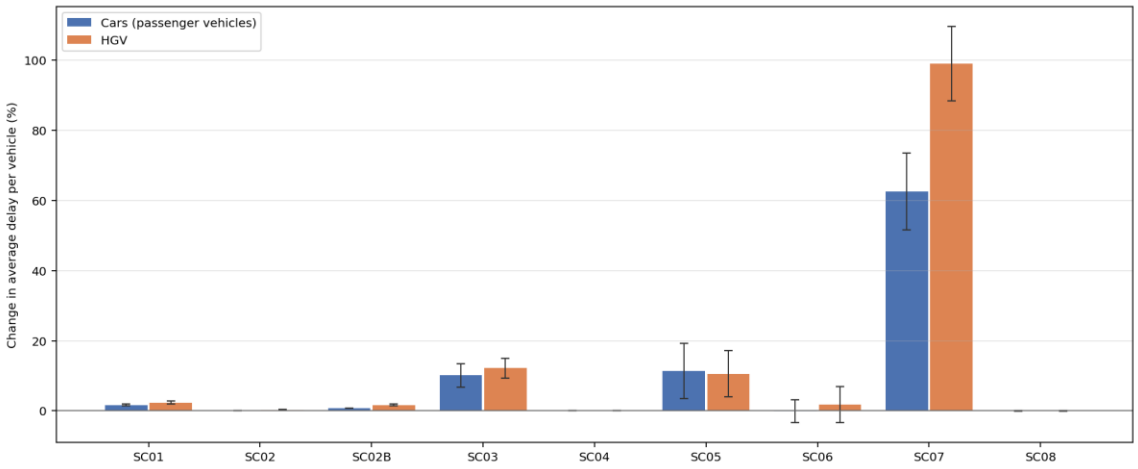


Figure 97. AM Peak: Paired Change in Average Delay per Vehicle — Cars vs HGV

During the PM peak, as presented in **Figure 98**, SC07 again produces the largest increases (about 43% for cars and 57% for HGVs on average, with the HGV increase larger on both seeds). For the corrected SC03, network-wide average delay per vehicle increases by about 6% for both classes; on the northbound sections that pass through the incident, however, HGV travel times rose by about 229% and 171% during the incident period (3,000 to 5,400 seconds), compared with 125% and 150% for passenger vehicles on all seeds. SC01 shows lower average delay than the reference; as noted above, this difference arises later in the period rather than during the incident and is not interpreted as a benefit of the incident.

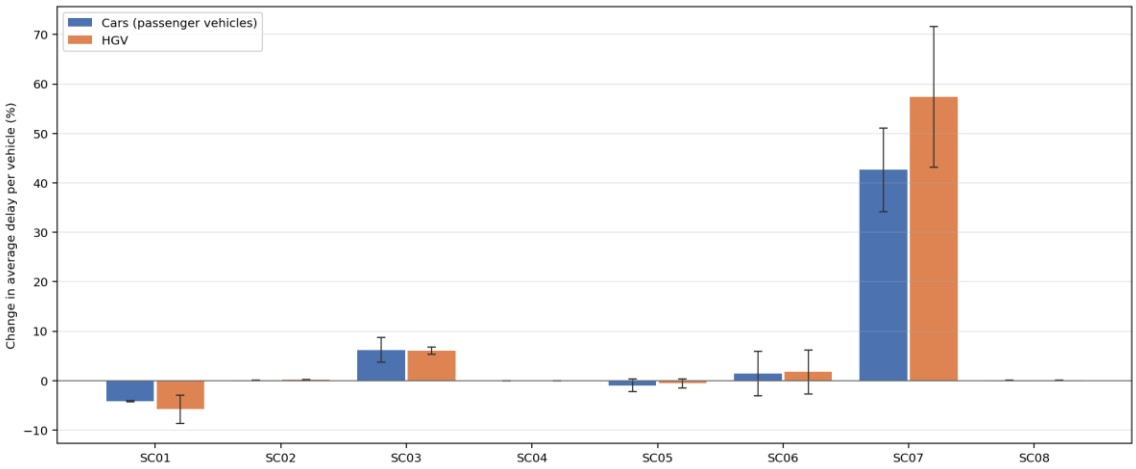


Figure 98. PM Peak: Paired Change in Average Delay per Vehicle — Cars vs HGV

These vehicle-class differences should be interpreted together with roadway exposure. In the model, the express-lane inputs carry passenger vehicles only, and HGVs account for about 1% of vehicles counted at the express-lane detectors compared with about 2.7% at the general-purpose lane detectors; the passenger-vehicle averages therefore include many express-lane users who are little affected by a GP-lane incident. Much of the apparent vehicle-class difference reflects the

greater exposure of HGVs, which remain in the general-purpose lanes where the incidents occur. On comparable sections used by both vehicle classes, the differences are much smaller for SC07, whereas for AM SC03 the HGV increase remains larger, consistent with the incident occupying the two right-hand GP lanes (Appendix U, Table 137). In selected severe scenarios, including SC07 and AM SC03, HGV delay per vehicle increased proportionally more than passenger-vehicle delay in both available seeds. The simulations do not isolate vehicle-performance mechanisms such as acceleration or braking, and no such causal attribution is made.

5.8 Summary of Incident Findings

Table 131 in Appendix U summarizes the qualitative grouping of the incident effects. A strict numerical ranking below SC07 is not supported by two paired seeds; the groups reflect effects that are consistent across both seeds. The analysis supports the following conclusions:

(1) Incident effects vary strongly with scenario configuration. Multi-lane and long-duration GP blockages produce clear network-wide delay, whereas several localized disruptions have negligible network-wide effects.

(2) SC07, the long-duration two-lane southbound GP near-blockage, is clearly the most disruptive tested incident in both peak periods (mean in-network delay increases of +529.6 and +405.1 veh-h per interval in the AM and PM peaks).

(3) Clear/moderate scenarios such as AM SC03 and the corrected PM SC03 produce measurable operational degradation, with incident-window increases of about 160 to 350 veh-h on the individual seeds.

(4) SC02, SC04 and SC08 produce negligible network-wide effects under the tested conditions; the incident location itself slows, but the effect remains local.

(5) SC06 has a meaningful temporary effect during the incident window in both peak periods (about 87 to 183 veh-h), but recovery after the incident substantially reduces its full-run net impact, which is not distinguishable from zero with the available seeds.

(6) AM SC05 shows a positive impact in both available paired runs, but its magnitude is sensitive to the random seed (incident-window increases of 223.3 and 77.8 veh-h).

(7) Severe incidents can generate substantial latent (unserved) demand that is not captured by in-network delay alone; for SC07 the derived expanded system impact is about twice (AM) to nearly four times (PM) the in-network effect.

(8) HGVs can experience disproportionate impacts because they remain in the GP lanes where the incidents occur and therefore have different roadway exposure; in SC07 and AM SC03, HGV delay per vehicle increased proportionally more than passenger-vehicle delay on both seeds, while on comparable sections the differences are smaller.

(9) The paired-seed results support scenario-level sensitivity conclusions but not highly precise statistical estimates of individual scenario magnitudes.

6 Limitations

It should also be noted that the current report does not include a full 24-hour model or off-peak period simulation; the analysis covers the AM and PM peak periods.

Also, for the current report, however, the incident scenarios were limited to localized lane disruptions where vehicles could generally maneuver around the affected area while experiencing speed reductions, delay, and localized congestion. Therefore, the analysis focused on the operational impacts of incident-related capacity and speed reductions rather than on network-wide path-choice responses.

7 Challenges

For this deliverable, it is important to acknowledge several challenges related to data availability and model readiness. The Research Team coordinated with FDOT Districts 4 and 6 and obtained multiple VISSIM model files. However, many of the available models are outdated, with some being more than 10 years old, and would require substantial geometric updates, additional traffic data collection, and further calibration before they could be used to represent current operating conditions. In addition, origin-destination data were available only for District 4 and were limited to 2015 base-year data with projections to 2020. As a result, developing reliable interpolations or extrapolations for current-year simulation conditions would be challenging and would require additional assumptions beyond the scope of this deliverable.

Part IV

Technical Review and Comparative Assessment of Available Express-Lane Simulation Models

SR 414, I-4 Ultimate, I-4 South, I-295 East, and I-295 West Model Packages

Part IV presents a technical review of five FDOT express-lane VISSIM model packages analyzed in support of FDOT federal-approval studies and project-development work. This review was conducted in parallel with the Deliverables 1 through 3 work and identifies which existing FDOT model packages are suitable for freight-mobility research, the data and re-run requirements needed before each package can be used, and the verified numerical findings available from the I-4 South SIMR model — the only package with directly accessible HGV performance results.

1 Introduction

1.1 Background

Florida manages an extensive network of express and managed lanes on SIS-designated Interstate facilities. Understanding the mobility effects of these facilities on freight-carrying vehicles — particularly heavy-goods vehicles (HGV) — is essential for corridor-level planning, investment prioritization, and policy development. Florida's freight transportation system is dominated by trucking, making HGV performance on SIS facilities a direct measure of statewide economic competitiveness.

VISSIM microsimulation models developed in support of federal-approval studies (SIMR) and project-development studies represent a potentially valuable resource for freight-mobility research. These models have been calibrated to field conditions and contain explicit representation of express-lane configurations, vehicle types, and multi-year demand forecasts. However, the extent to which these models are accessible, current, and suitable for freight research has not been systematically assessed.

1.2 Purpose and Research Context

This report presents a technical review of five FDOT express-lane VISSIM model packages to assess their fitness for quantitative freight-mobility research. The review addresses five central questions:

1. What model packages are available and in what formats?
2. Are the packages accessible without original-project software?
3. Do the packages represent HGV vehicle classes with sufficient fidelity?

4. What verified numerical findings can be extracted directly from each package?

5. In what sequence should the packages be engaged to advance freight research?

1.3 Scope

The review covers five corridors from two FDOT districts: SR 414/Maitland Boulevard and I-4 Ultimate and I-4 South (FDOT District 5, Orlando area), and I-295 East Express and I-295 West Express (FDOT District 2, Jacksonville area). All five corridors are included in Florida's SIS or provide direct access to SIS facilities.

The review was conducted through static analysis of extracted source files. No model was executed or modified. The analysis encompasses file-format identification; network architecture inspection via VISSIM INPX XML parsing; vehicle composition verification; managed-lane feature documentation; numerical extraction from accessible result databases; technical risk assessment; and model priority scoring.

2 Review Methodology

2.1 Source Packages

Two source archives were reviewed. The first, covering three District 5 corridors (SR 414, I-4 Ultimate, and I-4 South SIMR), contained approximately 1,304 files totaling 2.56 GB. The second, covering District 2 (I-295 East and West), contained approximately 1,462 files totaling approximately 1.76 GB. All analysis was performed on extracted files in a separate working directory. No original files were modified, renamed, or moved.

2.2 File Inspection and Format Identification

Each file type was identified through direct inspection. INPX network files (XML-based) were parsed using Python's ElementTree library, enabling complete extraction of simulation parameters, vehicle type definitions, managed-lane configurations, signal controller settings, and routing decision parameters. SQLite result databases were queried using Python's sqlite3 module, enabling direct extraction of vehicle-class-disaggregated performance measures. Binary SDF files were identified through binary header inspection and confirmed inaccessible by testing SQLite connection (which failed). Legacy binary INP files were confirmed unreadable without VISSIM 5.40 software. Text-format files including MLE managed-lane evaluation outputs and VBScript toll files were read directly.

2.3 Numerical Verification

All numerical values presented as verified findings were extracted directly from source files and, where applicable, independently recomputed. For the I-4 South SQLite result databases, the query filter used was WHERE ARG_VEHICLECLASS = '20' applied to the VEHICLENETWORKPERFORMANCEMEASUREMENT_EvaluationTimeIntervalClass table, with results restricted to the maximum time interval to obtain full-period averages. Ten-run means were computed arithmetically from all runs in each scenario's result set. Derived values (such as percentage reductions) were computed from two verified operands, both of which are reported.

Two corrections to previously reported values were identified and applied during this review: the I-4 South No-Build scenario link count was corrected from 1,241 to 1,090 based on re-parsing; and the total I-4 South stochastic run count was corrected from 120 to 100 based on SIMULATIONRUN table counts in all result databases.

2.4 Methodological Limitations

This review is based on archived source files. It does not constitute an independent field study or a model replication exercise. Performance results from proprietary binary SDF files are not presented because they cannot be independently accessed. All findings are conditioned on the accuracy and completeness of the archived files.

3 Overview of Available Models

3.1 Model Package Summary

The five reviewed model packages span approximately eight years of VISSIM software development, from legacy VISSIM 5.40 (circa 2014) through VISSIM 2022. They encompass both urban arterial/expressway configurations and Interstate freeway express-lane systems, providing a range of modeling approaches and levels of detail. Table 48 lists the reviewed facilities and model packages, and Table 49 gives an overview of each corridor and study.

Table 48. Reviewed Facilities and Model Packages

Corridor	FDOT District	Length (mi)	VISSIM Version	Primary Result Format	Analysis Years	Express-Lane Type
SR 414/Maitland Blvd	5 (Orlando)	~7	2021	PDF only	2019, 2025, 2045	Toll expressway (Car_EL type)
I-4 Ultimate	5 (Orlando)	~5	5.40 (legacy)	Binary .inp	2030	Unknown (binary format)
I-4 South SIMR	5 (Orlando)	~25	2022	SQLite .db	2022, 2030, 2050	Full EB+WB Express Lanes
I-295 East Express	2 (Jacksonville)	~5	7	SDF (binary)	2020, 2040	Speed-based dynamic toll EL
I-295 West Express	2 (Jacksonville)	~10-11	7/8.x	SDF (binary) + MLE text	2020, 2040	TTS-based dynamic toll EL

Table 49. Corridor and Study Overview

Corridor	Study Type	SIS Facility	Consultant	County	Stochastic Runs (total)
SR414/Maitland Blvd	PD&E Study	Toll expressway connector	Undisclosed	Orange	1 per scenario (12 total)
I-4 Ultimate	Design Support	Yes — SIS Interstate	Undisclosed	Orange/Seminole	1 per scenario (2 total)
I-4 South SIMR	SIMR (Federal Approval)	Yes — SIS Interstate	Kittelson & Associates	Orange/Osceola	10 per scenario (100 total)
I-295 East Express	SIMR Re-evaluation	Yes — SIS Freeway	Undisclosed	Duval	5–12 per scenario (52 total)
I-295 West Express	SIMR	Yes — SIS Freeway	Undisclosed	Duval	1 per Build scenario (critical)

3.2 File and Format Accessibility

The five packages vary substantially in the accessibility of their result data. The I-4 South SIMR package is the only one with fully accessible result databases. I-295 East and West results are in a proprietary binary format requiring PTV VISSIM to extract. I-4 Ultimate model files are in a legacy binary format requiring VISSIM 5.40 software. SR 414 results exist only in PDF summary

reports. Table 50 summarizes the scenarios and analysis years, and Table 51 the software and model versions.

Table 50. Scenario and Analysis-Year Summary

Corridor	Total Scenarios	Analysis Years	Peak Periods	Scenario Types
SR 414	12	2019, 2025, 2045	AM, PM	Existing, Build, No-Build, Build+Improvements
I-4 Ultimate	2	2030	AM, PM	Modified Build (ATC)
I-4 South SIMR	10	2022, 2030, 2050	AM, PM	Existing, Build (Express Lanes), No-Build
I-295 East	8	2020, 2040	AM, PM	Modified (Build), Original (No-Build)
I-295 West	14	2020, 2040	AM, PM	Existing, No-Build, Build 1 (1-lane EL), Build 2 (2-lane EL)
TOTAL	46	—	—	—

Table 51. Software and Model-Version Summary

Corridor	VISSIM Version	File Format	Result Format	Accessible Without VISSIM
SR 414	2021.00-03 / 2021.00-11	.inpx (XML)	PDF reports only	Partial — PDF summaries only
I-4 Ultimate	5.40-06 (circa 2014)	.inp (binary)	.kna/.net (partial)	No — binary .inp
I-4 South SIMR	2022.00-07 / 2022.00-08	.inpx (XML)	.db (SQLite)	YES — fully accessible
I-295 East	7	.inpx (XML)	.sdf (binary)	No — SDF binary
I-295 West	7 (Exist.) / 8.x (future)	.inpx (XML)	.sdf (binary) + .mle (text)	Partial — MLE facility-level only

4 I-4 and SR 414 Model Packages

4.1 SR 414/Maitland Boulevard

4.1.1 Corridor and Study Description

SR 414 (Maitland Boulevard) is a tolled expressway in Orange County operated by the Central Florida Expressway Authority, under FDOT District 5 jurisdiction for the reviewed PD&E study. The model covers approximately 7 miles from the Keene Road western connection to Gateway Drive, including 12 signalized intersections at the at-grade arterial connection. The study evaluates the SR 414 Expressway Extension across existing conditions (2019) and future design years (2025, 2045) under Build and No-Build alternatives.

4.1.2 Model Configuration

The INPX files were developed in VISSIM 2021. The network contains 568 to 608 links and 12 to 13 signal controllers. A dedicated Car_EL vehicle type (vehicle type 101, class 11) tracks express or toll-lane users separately from standard vehicle classes. HGV vehicle types (type 200,

class 20; type 1202, class 122) are present in the network. Each scenario contains a single stochastic run.

4.1.3 Results Availability and Limitations

SR 414 stores all simulation results as PDF turning-movement and intersection-delay summary reports. No SQLite, ATT, or equivalent result database is present in the archive. Vehicle-class disaggregated performance cannot be extracted. The calibration report is a scan-based PDF from which calibration statistics cannot be retrieved without optical character recognition. One peak volume value is confirmed from a text-extractable result PDF: 10,975 vehicles per hour at the Hope Road intersection in the 2045 AM Build scenario.

4.1.4 Research Relevance

SR 414 provides useful supporting operational material for the study corridor. Its direct relevance to express-lane freight analysis is limited compared with I-4 South and I-295 due to the shorter corridor length, absence of a raw result database, and single run per scenario. The package is rated as supplementary use.

4.2 I-4 Ultimate

4.2.1 Corridor and Study Description

The I-4 Ultimate project represents a major reconstruction of approximately 5 miles of the I-4 downtown Orlando corridor. The reviewed models are design-support simulations from approximately 2014 covering a 2030 analysis year with Modified Build adaptive traffic control. I-4 is a SIS-designated interstate.

4.2.2 Accessibility Limitations

The I-4 Ultimate model files are stored in VISSIM 5.40-06 legacy binary format, which cannot be read without the original VISSIM 5.40-06 software. All network geometry, vehicle types, express-lane configuration, demand inputs, and signal timing are inaccessible. The project uses RBCGUI for signal timing, introducing an additional software dependency. The package uses a legacy VISSIM environment, and compatibility and conversion must be verified before any research use.

4.2.3 Research Relevance

The I-4 Ultimate package cannot be assessed for HGV-specific performance in its current accessible form. Express-lane configuration is unknown. These models are approximately 12 years old and designed primarily for signal and interchange evaluation rather than express-lane freight analysis. This package is not recommended for freight research until VISSIM 5.40 software access is obtained or the files are converted to current format.

4.3 I-4 South SIMR

4.3.1 Corridor and Study Description

The I-4 South Systems Interchange Modification Report covers approximately 25 miles of I-4 from US 27 (Clermont area) east to Sand Lake Road, traversing 10 major interchanges including SR 50, SR 429, SR 528 (BeachLine Expressway), and SR 482. The project adds full-length I-4 Express Lanes in both eastbound and westbound directions. FDOT District 5. Study consultant: Kittelson & Associates, Inc.

The SIMR is a federal-approval document reviewed by FHWA prior to construction approval. The VISSIM models were developed in support of traffic operations analysis for federal review and contain formal calibration to existing conditions.

4.3.2 Model Configuration

Models were developed in VISSIM 2022. Network link counts vary by scenario: 996 links in the Existing 2022 base model; 1,241 links in the Build scenarios; and 1,090 links in the No-Build scenarios. The 151-link difference between Build and No-Build represents the physical express-lane infrastructure added in Build scenarios. Each scenario includes 10 stochastic runs for a total of 100 runs across the 10 scenarios. The simulation period is 16,200 seconds (4.5 hours) with a 3,600-second warm-up period.

4.3.3 Express-Lane Architecture

The I-4 South Build INPX files include explicit express-lane infrastructure: approximately 14 Decision Points (DCPs 100 through 114) covering eastbound and westbound access, egress, ingress, and entry nodes. Network links are explicitly named I-4 Express in both directions. No toll pricing objects or toll decision elements were identified in any I-4 South INPX file. The express lanes in the model operate on travel-time-based routing without explicit pricing. No explicit vehicle-class filter restricting HGV access to the express lanes was found, though this cannot be confirmed as intentionally permissive without a complete routing decision parameter inspection.

4.3.4 HGV Representation

HGV vehicle type 200, vehicle class 20, is present in all I-4 South INPX files. The SQLite result databases record performance measures disaggregated by vehicle class, enabling direct extraction of HGV delay and speed. HGV-specific results are obtained by filtering the VEHICLENETWORKPERFORMANCEMEASUREMENT_EvaluationTimeIntervalClass table where the vehicle class is 20 and the time interval is the maximum (full simulation period). Table 52 summarizes the express-lane and tolling features, Table 53 the HGV and freight representation by corridor, and Table 54 the calibration documentation and results availability.

Table 52. Express-Lane and Tolling Features

Corridor	Express-Lane Method	Toll Type	Toll Range	HGV EL Access	Diversion Model
SR 414	Car_EL vehicle type	None (type separation)	N/A	Unknown	Vehicle type routing
I-4 Ultimate	Unknown (binary format)	Unknown	Unknown	Unknown	Unknown
I-4 South (Build)	DCPs 100–114 EB+WB	None modeled	N/A	No exclusion found	Travel-time routing
I-295 East (Build)	39 ML facilities, 11 routing decisions	Speed-based dynamic	$0.50–$5.00	Explicitly permitted	VISSIM logit (logitA=0.5)
I-295 West (Build)	3 ML facilities, VBScript	TTS-based VBScript	~$0.12–$4.30	Restricted (policy unconfirmed)	VBScript Delta table

Table 53. HGV and Freight Representation by Corridor

Corridor	HGV Type	HGV Class	HGV Composition	SIS Facility	HGV Results Accessible
SR 414	200, 1202	20, 122	Not confirmed	Possible (toll expressway)	No — PDF only
I-4 Ultimate	Unknown	Unknown	Unknown	Yes	No — binary
I-4 South	200	20	Not confirmed	Yes	YES — SQLite
I-295 East	200	20	3.5% confirmed	Yes	No — SDF binary
I-295 West	200	20	5.0% confirmed	Yes	Partial — MLE only

Table 54. Calibration Documentation and Results Availability

Corridor	Calibration Report	Format	GEH Accessible	Result Database	Vehicle-Class Results
SR 414	SR 414 PD&E Calibration Report (Jan 2022)	Scan-based PDF	No — OCR required	None	No
I-4 Ultimate	Not found in archive	N/A	N/A	None	No
I-4 South	Separate SIMR document (not in archive)	Unknown	Unknown	100 SQLite .db files	Yes — class 20
I-295 East	Calibration Report (May 2014) — text-extractable	Text PDF	Partial — GEH tables in images	80 SDF (binary)	No
I-295 West	SIMR appendices — scan-based PDF	Scan-based PDF	No — OCR required	140 SDF (binary) + 80 MLE	Partial (MLE only)

5 I-295 East and West Model Packages

5.1 I-295 East Express

5.1.1 Corridor and Study Description

I-295 East Express Phase I covers approximately 5 miles of I-295 from SR 9B (south terminus) to SR 202/JTB Boulevard (north terminus) in Duval County under FDOT District 2 jurisdiction (FPID 209301-3-52-01). The corridor carries approximately 91,400 to 107,000 vehicles per day based on 2013 base-year counts. The project adds express lanes: two lanes per direction from SR 9B to Gate Parkway, transitioning to one lane per direction from Gate Parkway to JTB Boulevard.

5.1.2 Model Configuration

Eight INPX files were reviewed, all developed in VISSIM 7. Network links range from 1,067 to 1,075 per scenario. Build scenarios contain 39 managed-lane facilities per scenario. The simulation period is 19,800 seconds (5.5 hours). Stochastic runs range from 5 to 12 per scenario, meeting or exceeding the FDOT minimum of 5 runs.

5.1.3 Express-Lane Architecture and HGV Access

The I-295 East model includes a full managed-lane implementation with speed-based dynamic toll pricing. Tolls range from $0.50 to $5.00 across 7 speed bands and update every 900 seconds (15 minutes). Route choice uses VISSIM's native logit diversion model with parameters logitA=0.5, cost coefficient −0.61, and travel-time coefficient +0.49. The managed-lane routing decisions are configured with allVehTypes=true, meaning all vehicle types — including HGV — are eligible for express-lane use. HGV composition is confirmed at 3.5 percent. HGVs are not explicitly excluded through the reviewed managed-lane facility setting; this does not prove that HGVs actually used the express lanes, but confirms the model is configured to permit their access.

An apparent template error is present in all eight INPX files: the simulation comment field reads 'ATC 1B – 2040 PM' regardless of the scenario. This suggests some scenario-specific parameters may not have been updated individually, and this should be confirmed with the model developer.

5.1.4 Results Availability

All 80 I-295 East result files use a proprietary PTV VISSIM binary format (.sdf). This format was confirmed inaccessible through binary header inspection and direct database connection testing. No text-format result output is present in the package. All East Express performance data — including HGV delay, express-lane volumes by vehicle class, and toll revenue — are inaccessible without PTV VISSIM software. This is the primary limitation for freight research use of the East package. No I-295 East performance results are presented in this report.

5.2 I-295 West Express

5.2.1 Corridor and Study Description

I-295 West Express Phase 1 covers approximately 10 to 11 miles of I-295 from SR 13/San Jose Boulevard (east terminus) to I-95 (west terminus) in Duval County under FDOT District 2 jurisdiction (FPID 213345-7-22-01). The project evaluates two build alternatives: Build 1 (one express lane per direction) and Build 2 (two express lanes per direction). Analysis years are 2020 and 2040.

5.2.2 Model Configuration

Fifteen INPX files were reviewed. The Existing model uses VISSIM 7. All future-year models use VISSIM 8.x (version code 101 in INPX attributes), representing a major software version change from the calibrated Existing model. This version change may affect behavioral parameters and should be confirmed with the model developer. Network links range from 1,066 to approximately 1,170 depending on scenario. HGV composition is confirmed at 5.0 percent, the highest of the five reviewed corridors.

5.2.3 Stochastic Sampling — Critical Deficiency

All eight I-295 West Build scenarios — Build 1 and Build 2 across 2020 and 2040 AM and PM periods — contain one stochastic run each. This was confirmed by inspecting the numRuns attribute in all relevant INPX files. The FDOT standard minimum is five stochastic runs per scenario. With a single run, no confidence intervals can be computed, stochastic variability cannot be characterized, and the observed result may not represent average network conditions. The available Build results may support model inventory and methodology planning, but are not adequate for quantitative operational conclusions. Re-running all Build scenarios with a minimum of five random seeds, documented for comparability, is required before these results can be used for research.

The I-295 West No-Build future-year scenarios are also under-sampled: 2020 scenarios contain 2 runs each, the 2040 AM No-Build contains 1 run, and the 2040 PM No-Build contains 3 runs.

5.2.4 Express-Lane Architecture and Tolling

The West package includes three managed-lane facilities per Build scenario, corresponding to eastbound, westbound segment 1, and westbound segment 2 alignments. Tolls are calculated by an external VBScript called at each 9,000-second update interval (150 minutes). The toll is determined from a lookup table as a function of travel time in system and segment length, approximating $0.04 per minute of travel time. Three functionally identical VBScript files were authored by RS&H/Kiel Ova in 2014 — one file per facility, differing only in the facility identifier. Managed-lane routing decisions use allVehTypes=false, meaning HGV access is restricted, though the specific vehicle classes permitted were not fully confirmed from the archived files.

The managed-lane facility names in the model reference 'I-10 EB/WB,' which is a naming artifact. The facilities represent I-295 alignments. Similarly, the existing West model uses random seed 42 for the PM period, while all future-year models use seed 1.

5.2.5 MLE Text Output

The I-295 West Build scenarios produce managed-lane evaluation text output files (.mle), one per facility per run. These files report travel time in system, average managed-lane speed, toll rate, total revenue, managed-lane vehicle count, and general-purpose vehicle count at each time step. Because only one run exists per Build scenario, these values are single-run observations and are not statistically representative. They may be used for model configuration verification and methodology development but not for quantitative comparison. Table 55 summarizes the principal limitations of the I-295 East and West packages.

Table 55. I-295 East and West Principal Limitations

Issue	I-295 East	I-295 West
Result accessibility	All results in SDF binary — inaccessible without PTV VISSIM	SDF binary inaccessible; MLE provides facility-level only
Stochastic runs (Build)	5–12 runs — adequate	1 run per scenario — CRITICAL DEFICIENCY
Stochastic runs (No-Build)	5 runs — adequate	1–3 runs — under-sampled
HGV in ML	Explicitly permitted (allVehTypes=true)	Restricted (allVehTypes=false); specific classes not confirmed
VISSIM version	Version 7 throughout — consistent	Version 7 (Existing) to version 8.x (future) — major version change
Naming artifact	Comment field: 'ATC 1B – 2040 PM' in all scenarios	ML facilities named 'I-10 EB/WB' in I-295 model
Primary SDF PDFs	SIMR (45.5 MB) — scan-based; text not accessible	SIMR (69 MB) + Appendices (42.8 MB) — scan-based

5.3 East versus West Comparison

While both I-295 corridors are SIS-designated freeway facilities in Duval County, they differ substantially in managed-lane modeling approach and data quality. The East package uses VISSIM's native logit diversion with speed-based tolling, has higher stochastic sampling, and explicitly permits HGV express-lane access. The West package uses an external VBScript toll model with a longer update interval, has a critical sampling deficiency in Build scenarios, and restricts ML access by vehicle class. The West corridor has the higher HGV composition (5.0 percent versus 3.5 percent). Once the East results are exported and the West Build scenarios are rerun, the two packages support a direct policy comparison of permissive versus restrictive HGV express-lane access policies in the same metropolitan area.

6 Comparative Model Assessment

6.1 Assessment Framework

Each model package was assessed against 12 criteria relevant to freight-mobility research. Scores of 1 through 5 were assigned based on the strength of evidence from source-file inspection. A weighted assessment was computed using the criterion weights listed in Table 56. The weighted scores support the research priority recommendations in Chapter 8 but are intended to complement, not replace, technical judgment about each model's fitness for a specific research question.

Table 56. Comparative Freight-Research Suitability

Assessment Criterion	Weight	SR 414	I-4 Ultimate	I-4 South	I-295 East	I-295 West
Express-Lane Representation	15%	2	N/A	5	4	3
Freight/HGV Representation	15%	2	N/A	5	3	3
Truck-Specific Output Access	10%	1	1	5	1	2
Route-Choice Capability	10%	2	N/A	3	4	3
Calibration Documentation	10%	2	2	4	3	2
Results Accessibility	10%	1	1	5	1	2
Stochastic Run Adequacy	10%	1	1	5	4	1
Tolling Representation	5%	2	N/A	1	4	4
Incident Capability	5%	1	N/A	2	2	2
Software Compatibility	5%	4	1	5	3	3
Ease of Modification	5%	3	1	4	3	3
Weighted Score (/ 5.0)	100%	1.70	1.10	4.10	2.65	2.30

Note: N/A indicates criterion could not be scored due to inaccessible binary format. I-4 Ultimate N/A entries were excluded from the weighted score computation.

Figure 99 presents a color-coded matrix comparing the five reviewed model packages against the six highest-weight criteria used in the suitability assessment above. This matrix supplements Table 56 by making the pattern of per-criterion strengths and limitations immediately visible. Scores range from 1 (lowest suitability) to 5 (highest). Cells marked N/A indicate criteria that could not be scored because model files are in an inaccessible binary format.

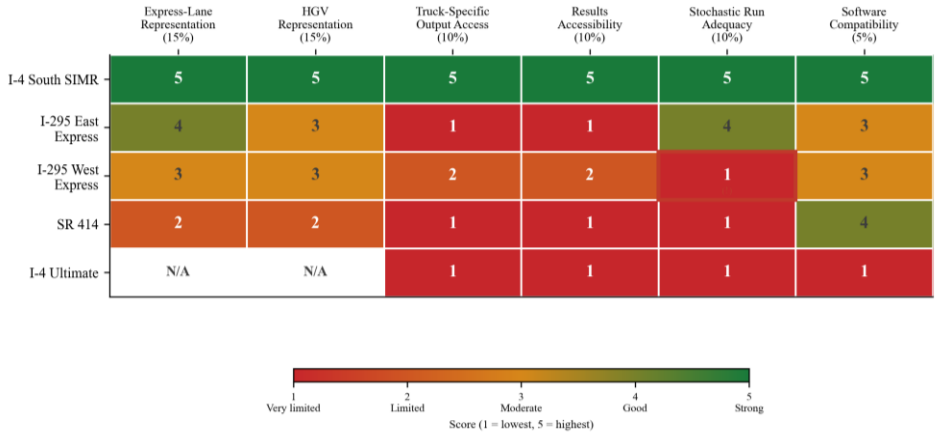


Figure 99. Comparative Freight-Research Suitability Assessment: Six Key Criteria

Source: FDOT_Model_Research_Priority_Scoring.csv. Six highest-weight criteria shown; see Table 56 for the full assessment. (!) = CRITICAL limitation: I-295 West Stochastic Run Adequacy = 1 run per Build scenario. N/A = criterion not scoreable from binary files.

The heatmap confirms that I-4 South SIMR is the only package scoring 5 across all six displayed criteria, reflecting full accessibility of model files and vehicle-class-disaggregated results. I-295 East scores well on most criteria but receives a score of 1 on Truck-Specific Output Access and Results Accessibility, both of which would improve to 4 or 5 following SDF export. I-295 West's single run per Build scenario produces a score of 1 on Stochastic Run Adequacy — the most significant current barrier to quantitative use. SR 414 and I-4 Ultimate have broadly low or unscoreable entries.

Stochastic run adequacy is among the most operationally significant differences across the five reviewed packages. Figure 100 presents the minimum number of stochastic runs per Build scenario for each corridor, alongside the FDOT standard minimum of five runs. A single stochastic run does not permit computation of confidence intervals or reliable characterization of network performance variability, and Build-versus-No-Build differences based on one run each cannot be tested for statistical significance.

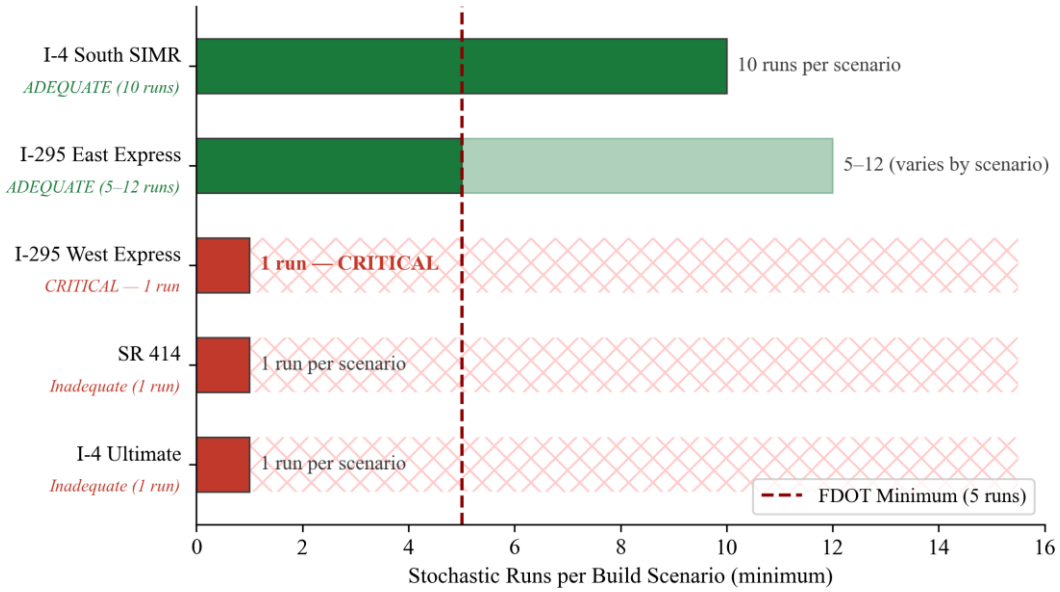


Figure 100. Stochastic Run Adequacy by Corridor: Build Scenarios

Source: FDOT_Master_Scenario_Matrix.csv; INPX numRuns attribute confirmed for all Build scenarios. FDOT minimum: 5 runs per scenario. I-295 East: 12 runs for 2020 scenarios; 5 runs for 2040 scenarios. I-295 West Build: 1 run in all 8 Build scenarios (RISK-002, CRITICAL). SR 414 and I-4 Ultimate: inferred from scenario matrix (binary format prevents direct INPX confirmation).

Only I-4 South SIMR (10 runs) and I-295 East Express (5–12 runs) meet the FDOT minimum threshold. I-295 West Express, SR 414, and I-4 Ultimate each have one run per Build scenario. For I-295 West, this deficiency is compounded by inaccessible SDF result files and a VISSIM version change between calibration and future-year models. The I-295 West Build deficiency is classified as a critical barrier to quantitative use and requires remediation (action RR-01) before any Build-versus-No-Build comparison can be derived from that package.

Figure 101 presents the 12-criterion weighted suitability score for each of the five reviewed model packages. The weighted score (out of 5.0) integrates all criteria in Table 56 and reflects the degree to which each package is ready for immediate freight-mobility research use. Post-remediation estimates, derived from the key-action analysis in Table 57, illustrate the potential improvement in research suitability if identified actions are completed.

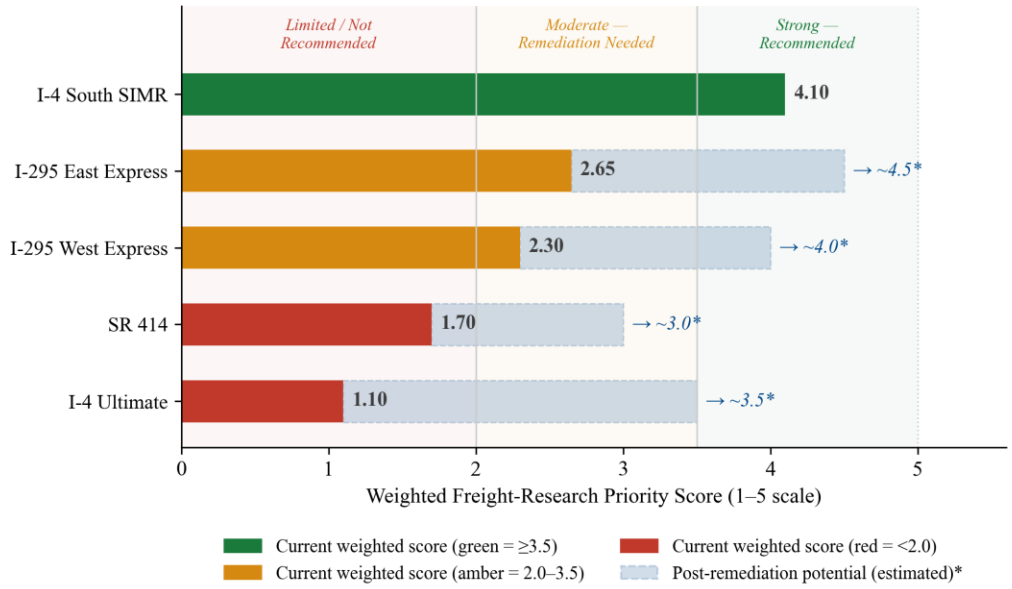


Figure 101. Freight-Research Priority Scores: Current and Post-Remediation Potential

*Source: FDOT_Model_Research_Priority_Scoring.csv (12-criterion weighted assessment). Criterion weights: Express-Lane Representation 15%, Freight/HGV Representation 15%, Truck-Specific Output Access 10%, Results Accessibility 10%, Stochastic Run Adequacy 10%; remaining criteria 5% each. * Post-remediation values are qualitative estimates (see Table 57), not re-scored values.*

I-4 South SIMR is the only package with a current weighted score above 4.0 (4.10/5.0), reflecting its fully accessible SQLite databases, 10 stochastic runs per scenario, and explicit HGV-class output. I-295 East scores 2.65 currently but is estimated to reach approximately 4.5 following SDF export — a single data-request action (DR-05) that would unlock the entire package for analysis. I-295 West shows similar post-remediation potential but requires both additional stochastic runs and SDF export. SR 414 and I-4 Ultimate have the lowest current scores, both facing fundamental result-accessibility barriers. Weighted scores support, but do not replace, technical judgment in selecting models for specific research questions.

Table 57. Recommended Model Priority — Weighted Assessment

Model	Weighted Score	Current Rating	Post-Remediation Estimate	Key Action Required
I-4 South SIMR	4.10 / 5.0	STRONG — use immediately	No change needed	None for HGV analysis
I-295 East Express	2.65 / 5.0	LIMITED — results inaccessible	~4.5 after SDF export	Request result export (no rerun needed)
I-295 West Express	2.30 / 5.0	POOR — 1 run per Build	~4.0 after rerun + SDF export	Rerun Build scenarios (≥5 seeds)
SR 414	1.70 / 5.0	POOR — PDF results only	~3.0 after rerun + DB export	Request result database export
I-4 Ultimate	1.10 / 5.0	VERY POOR — binary format	~3.5 if VISSIM 5.40 obtained	Obtain legacy VISSIM or convert files

7 Verified Findings

7.1 I-4 South HGV Network-Delay Findings

The I-4 South SQLite result databases support direct extraction of HGV network-delay and speed measures disaggregated by vehicle class. Table 58 presents the verified 10-run arithmetic means for HGV (vehicle class 20) network-average delay and speed for each scenario. These values were extracted from all 100 result databases across the 10 scenarios and have been independently verified.

Table 58. Verified I-4 South HGV Network-Delay Findings

Scenario	Analysis Year	Period	HGV Avg. Delay (sec)	HGV Avg. Speed (km/h)	All-Veh. Avg. Delay (sec)	Source / Verification
Existing	2022	AM	115.2	68.8	83.7	Verified — 10 SQLite DBs
Existing	2022	PM	386.6	45.8	396.9	Verified — 10 SQLite DBs
Build (Express Lanes)	2030	AM	249.2	56.4	222.9	Verified — 10 SQLite DBs
No-Build	2030	AM	616.7	31.2	421.5	Verified — 10 SQLite DBs
Build (Express Lanes)	2030	PM	669.2	29.7	—	Verified — 10 SQLite DBs
No-Build	2030	PM	890.5	21.8	—	Verified — 10 SQLite DBs
Build (Express Lanes)	2050	AM	1,189.6	15.2	—	Verified — oversaturated
No-Build	2050	AM	1,334.1	12.6	—	Verified — oversaturated
Build (Express Lanes)	2050	PM	1,126.2	16.4	—	Verified — oversaturated
No-Build	2050	PM	1,399.2	11.0	—	Verified — oversaturated

Source: VEHICLENETWORKPERFORMANCEMEASUREMENT_EvaluationTimeIntervalClass table in all I-4 South SQLite result databases. Filter: vehicle class 20; maximum time interval (full simulation period average). Run count: 10 per scenario; values are arithmetic means.

7.2 Build versus No-Build Comparison

The I-4 South Build scenarios — which include full eastbound and westbound I-4 Express Lanes — are associated with lower modeled HGV network delay than the corresponding No-Build scenarios across all four Build-versus-No-Build pairs: The modeled delay comparison is shown in the figure in the Master Executive Summary (Figure 1 of this master report).

2030 AM: Approximately 60 percent lower HGV delay in the Build scenario (249.2 seconds) than in the No-Build scenario (616.7 seconds).

2030 PM: Approximately 25 percent lower HGV delay in the Build scenario (669.2 seconds) than in the No-Build scenario (890.5 seconds).

2050 AM: Approximately 11 percent lower HGV delay in the Build scenario (1,189.6 seconds) than in the No-Build scenario (1,334.1 seconds).

2050 PM: Approximately 20 percent lower HGV delay in the Build scenario (1,126.2 seconds) than in the No-Build scenario (1,399.2 seconds).

7.3 Important Caveats

These are modeled Build-versus-No-Build associations, not independent measurements. Static inspection of the INPX files cannot determine whether the observed delay reduction results from direct HGV express-lane use, indirect general-purpose lane congestion relief, or other improvements included in the Build network that are not present in the No-Build network. The I-4 South models do not include toll pricing logic; the express lanes operate on travel-time-based routing only. Querying express-lane data-collection points (DCPs 100 through 114) by HGV vehicle class in the Build scenario result databases is the recommended next step to isolate the direct-use component.

The 2050 network conditions are oversaturated across both Build and No-Build scenarios, with network-average speeds below 20 km/h and average delays exceeding 1,100 seconds for HGVs. The 2050 Build versus No-Build comparisons are directional indicators only and should not be interpreted as reliable absolute performance estimates.

No I-295 East or I-295 West performance results are presented. East results are in inaccessible SDF binary files. West Build results are based on single stochastic runs and are not adequate for quantitative comparison.

8 Model Selection and Recommended Research Approach

8.1 Model Recommendations

Based on the comparative assessment, the following model-use priorities are recommended:

Primary Model — I-4 South SIMR: The only fully accessible freight-relevant model in the reviewed archive. Use immediately for Build versus No-Build HGV analysis on a 25-mile SIS Interstate with full express-lane representation and 100 stochastic runs in directly queryable format.

Secondary Model — I-295 East Express (after data extraction): High structural value. HGV express-lane access is confirmed; stochastic sampling is adequate; dynamic toll-logit model is complete. A single data request for SDF result export converts this package from inaccessible to fully usable without model re-runs.

Remediation Required — I-295 West Express: High long-term value, particularly for toll-policy research and the contrast between restrictive and permissive HGV express-lane access policies. Cannot be used quantitatively until Build scenarios are rerun with a minimum of five random seeds.

Supplementary — SR 414/Maitland Boulevard: Useful for corridor context and calibration comparison but limited for express-lane freight analysis without result database export.

Not Recommended at Present — I-4 Ultimate: Inaccessible without legacy VISSIM 5.40 software. Approximately 12 years old. Not recommended for freight research until files are converted or original software is obtained.

8.2 Staged Research Strategy

The following four-stage approach is recommended to advance from the current archive review to full multi-corridor freight analysis:

Stage 1 — Model Access and Dependency Verification: Query I-4 South express-lane data-collection points by HGV class. Confirm I-4 South model is the approved SIMR submission version. Request result export for I-295 East. Obtain VISSIM version information for any planned re-runs.

Stage 2 — Result Extraction and Reruns: Extract I-295 East results via PTV VISSIM after data request is fulfilled. Commission I-295 West Build reruns (minimum 5 seeds). Apply optical character recognition to scan-based SIMR calibration documents.

Stage 3 — Freight-Scenario Development: Develop HGV-priority research scenarios on I-4 South. Modify routing or add toll pricing logic to test policy alternatives. Develop comparable scenarios on I-295 East and West once results are accessible.

Stage 4 — Comparative Analysis and Documentation: Combine findings across I-4 South, I-295 East, and I-295 West for a multi-corridor analysis of express-lane freight effects on Florida SIS facilities. Document results against verified baseline values in this report.

Overall, I-4 South SIMR is the only package that passes all four evaluation gates without requiring remediation — it is immediately usable for freight-mobility research. I-295 East passes three gates but requires SDF result export (data request D5) before quantitative analysis can proceed. I-295 West fails the stochastic adequacy gate (one Build run per scenario; action RR-01) and also requires SDF export. I-4 Ultimate is not recommended due to its legacy binary format; SR 414 is suitable for supplementary corridor context only. The staged research strategy in Section 8.2 describes the recommended sequence for advancing through these gates.

9 Data, Software, and Model Requests

The following requests are recommended to support research use of the reviewed packages.

Table 59. Recommended Data Requests and Model Reruns

ID	Corridor	Item Requested	From	Priority	Justification
DR-05	I-295 East	PTV VISSIM result export — all 80 SDF files to CSV or SQLite	East model developer	CRITICAL	All East performance data inaccessible without this export
RR-01	I-295 West	Re-run all 8 Build scenarios — minimum 5 comparable random seeds	West model developer	CRITICAL	1-run Build results are statistically insufficient
DR-01	I-4 South	Confirmation of HGV express-lane routing eligibility (vehicleClass on DCPs 100–114)	Kittelson & Associates	HIGH	Cannot isolate direct HGV EL use from static inspection
DR-06	I-295 East	Confirmation that HGV ML eligibility (allVehTypes=true) reflects approved policy	FDOT District 2	HIGH	Need to confirm HGV access is policy-consistent
RR-02	I-295 West	Re-run No-Build future scenarios to match Build run count (min 5 seeds)	West model developer	HIGH	Under-sampled No-Build limits Build/No-Build comparison
DR-10	I-295 West	Specific vehicle classes permitted in West managed-lane routing decisions	FDOT D2 / developer	HIGH	allVehTypes=false confirmed; specific classes not extracted
DR-11	I-295 West	PTV VISSIM result export — all 140 West SDF files	West model developer	HIGH	MLE covers facility level only; network MOE needs SDF
DR-17	I-4 South	Guidance on querying DCP 100–114 tables by ARG_VEHICLECLASS=20	Kittelson & Associates	HIGH	Needed to isolate direct HGV express-lane volumes
DR-04	I-4 South	Confirmation that archived INPX files are the SIMR-approved versions	Kittelson & Associates / FDOT D5	HIGH	Ensure working files are the approved submission
DR-07	I-295 East	Calibration GEH statistics in machine-readable form	FDOT District 2	MEDIUM	Calibration acceptance not extractable from PDF images

Table 59. Recommended Data Requests and Model Reruns (continued)

ID	Corridor	Item Requested	From	Priority	Justification
DR-13	I-295 West	Documentation of VISSIM parameter transfer from v7 (Existing) to v8.x (future)	West model developer	MEDIUM	Version change affects comparability of results
DR-14	I-4 Ultimate	VISSIM 5.40-06 access or INPX export of I-4 Ultimate models	FDOT D5 / PTV Group	MEDIUM	Binary .inp format unreadable without original software
DR-15	SR 414	SQLite or ATT result database exports from SR 414 models	FDOT D5 / Consultant	MEDIUM	PDF summaries insufficient for vehicle-class analysis

10 Limitations

10.1 Archived Source Files

All findings are based on archived source files. The review cannot confirm that the archived files are the final approved versions submitted for FHWA review, or that they match the models used to produce any officially reported findings. Confirmation that the archived INPX files are the approved SIMR submission versions is recommended as a first step for any research use.

10.2 Static Model Inspection

This review was conducted through static analysis without model execution. Some model parameters — particularly HGV routing eligibility, dynamic toll response, and certain signal timing attributes — can only be fully confirmed by running the models. Static inspection of INPX files can confirm the presence and configuration of model objects, but cannot confirm the runtime behavior of those objects under simulated traffic conditions.

10.3 Proprietary SDF Outputs

All 220 SDF result files (80 from I-295 East, 140 from I-295 West) are in a proprietary binary format that cannot be read without PTV VISSIM software. No performance findings are presented for these corridors. The limitation applies to all I-295 East and West network performance measures including delay, speed, queue length, and vehicle counts by vehicle class.

10.4 Legacy Software Dependency

The I-4 Ultimate models require VISSIM 5.40-06 and a compatible RBCGUI version. These are approximately 12-year-old software versions. All I-4 Ultimate model content is inaccessible without this software.

10.5 Inadequate Stochastic Runs

The I-295 West Build scenarios each contain one stochastic run. The I-295 West No-Build future-year scenarios contain one to three runs. These quantities are insufficient for characterizing stochastic variability. Any finding derived from these results should be treated as a single-point observation. The SR 414 and I-4 Ultimate packages also contain a single run per scenario.

10.6 HGV Express-Lane Mechanism

The I-4 South Build scenario models include full express-lane infrastructure but no toll pricing logic. The mechanism producing the observed HGV delay reduction — whether from direct HGV express-lane use or from general-purpose lane congestion relief — cannot be determined from static INPX inspection. Querying express-lane data-collection points for HGV class volumes is necessary to isolate the direct-use component.

10.7 Oversaturated 2050 Conditions

I-4 South 2050 scenarios show network-wide average speeds below 20 km/h and average HGV delays exceeding 1,100 seconds, indicating severe network oversaturation. Under these conditions, simulation models may not reliably represent traffic operations. The 2050 Build versus No-Build comparisons should be treated as directional indicators only.

10.8 Missing Calibration Documentation

Calibration reports for SR 414 and I-295 West are scan-based PDFs from which calibration statistics cannot be retrieved without optical character recognition. The I-4 South calibration report was not present in the reviewed archive. Calibration acceptance cannot be independently verified for three of the five corridors.

11 Conclusions

This technical review assessed five FDOT express-lane VISSIM microsimulation model packages representing 46 scenarios, 35 INPX network files, and approximately 2,766 extracted source files from two FDOT districts. The primary conclusions are as follows:

11.1 I-4 South SIMR

The I-4 South SIMR package is the recommended primary model for immediate freight-mobility research. It is the only package in the reviewed archive with fully accessible result databases, explicit HGV vehicle-class output, and adequate stochastic sampling. The Build scenarios are associated with approximately 60 percent lower modeled HGV network delay for the 2030 AM peak and approximately 25 percent lower for the 2030 PM peak compared to No-Build. These findings are verified from 100 SQLite result databases. The 2050 results are directional only due to network oversaturation. The mechanism driving the observed improvement cannot be determined from static inspection alone.

11.2 I-295 East Express

The I-295 East Express package is the recommended secondary model after performance data are exported. The package includes a complete dynamic managed-lane model with speed-based tolling, logit-based diversion, and explicit HGV express-lane access. Stochastic sampling is adequate. A single data request to the model developer for SDF result export would make the entire package accessible for freight research. Operational results are currently contained in proprietary binary SDF files and no I-295 East performance results are presented in this report.

11.3 I-295 West Express

The I-295 West Express package requires remediation before quantitative use. All eight reviewed Build scenarios contain one stochastic run, which is insufficient to characterize stochastic variability or support confidence interval estimation. Once re-runs are completed with a minimum of five seeds, the package offers strong value for toll-policy research — particularly for comparing restrictive and permissive HGV express-lane access in the same metropolitan corridor system as I-295 East. The higher HGV composition (5.0 percent) and readable VBScript toll logic make the West package well-suited for toll-elasticity analysis.

11.4 SR 414 and I-4 Ultimate

SR 414 provides useful supporting operational material for the study corridor. Its direct relevance to express-lane freight analysis is limited by the absence of a result database and the single run per scenario. I-4 Ultimate cannot be assessed without VISSIM 5.40 software or file conversion, and the models are approximately 12 years old. Neither package is recommended as a primary freight research resource in their current accessible form.

11.5 Overall Assessment

Together, the three viable packages — I-4 South, I-295 East (after export), and I-295 West (after rerun) — support a multi-corridor freight-mobility analysis of SIS express-lane facilities in two major Florida metropolitan areas. The primary near-term priority is to begin research using the I-4 South package and simultaneously initiate the data requests and reruns needed to unlock the I-295 packages.

11.6 Next Steps

As immediate next steps, the research team recommends calibrating the I-4 microsimulation model to reflect current roadway geometry, traffic operations, and express lane configurations. In parallel, the team should submit a data request to the appropriate FDOT district or model developer to obtain the most recent available version of the I-295 microsimulation model for use in the analysis.

Part V

Operational Strategy and Future Demand Scenarios

Task 4: Pricing Strategy and Demand Sensitivity Analysis — I-4 Corridor, 2040 PM Peak

Part V presents the operational strategy and future demand scenario analyses conducted under Task 4 of this research program. Both analyses use the VISSIM microsimulation model of the I-4 corridor with Express Lanes (EL) and general-purpose (GP) lanes under 2040 PM-peak conditions, and both evaluate freight through the travel time of heavy goods vehicles (HGV), which in the study model do not use the Express Lanes. Results are reported by direction, eastbound (EB) and westbound (WB). Chapter 1 (Subtask 4.2) evaluates Express Lane pricing strategies at baseline demand; Chapter 2 (Subtask 4.3) evaluates controlled increases in corridor demand with the existing pricing strategy; and Chapter 3 integrates the two analyses and states the Task 4 conclusions. Supporting technical material is provided in Appendix R (toll-bound pricing analysis), Appendix S (GP-responsive pricing analysis) and Appendix T (future demand analysis).

1 Operational Strategy Scenarios

1.1 Objective and Scenario Framework

Subtask 4.2 evaluates how Express Lane pricing strategies affect Express Lane use, toll revenue, GP lane operations and freight performance on the modeled I-4 corridor (2040 PM peak, VISSIM microsimulation). The pricing experiments address one question:

> *How do changes in pricing magnitude and in the congestion information used to set the toll affect Express Lane usage, revenue, GP operations and freight performance?*

The question was investigated in three steps, each motivated by the result of the previous one (Table 60):

1. **Reference.** The Reference Pricing Strategy (S1) establishes the benchmark for every comparison.

2. **Pricing magnitude.** Two toll-bound sensitivities lower and raise the toll bounds of the same controller: the Reduced Toll-Bound Scenario (S2_LOW) and the Increased Toll-Bound Scenario (S2_HIGH).

3. **Pricing information source.** The GP-Responsive Pricing Scenario (GP_RESP) keeps the pricing mechanics of S1 but sets tolls from GP-lane density instead of EL density. Three robustness scenarios repeat this change with reduced toll bounds (Reduced-Bound GP-Responsive Scenario,

GP_RESP_LOW), at 80% demand (Reduced-Demand GP-Responsive Scenario, GP_RESP_D80) and at 120% demand (Increased-Demand GP-Responsive Scenario, GP_RESP_D120). Each is paired with a matched EL-density-responsive comparator: S2_LOW, the 80% Demand EL-Density Comparator (D80_ELController) and the 120% Demand Scenario (D120), which is the increased-demand scenario of Subtask 4.3 (Chapter 2).

Table 60. Subtask 4.2 Pricing-Strategy Scenarios

Scenario	**Pricing concept**	**Toll bounds**	**Demand**	**Question addressed**	**Comparator**
Reference Pricing Strategy (S1)	EL-density-responsive	Standard (1.00x)	Baseline (116,159 veh)	Benchmark for every baseline-demand comparison	-
Reduced Toll-Bound Scenario (S2_LOW)	EL-density-responsive	0.70x	Baseline	Effect of lower toll magnitude	S1
Increased Toll-Bound Scenario (S2_HIGH)	EL-density-responsive	1.50x	Baseline	Effect of higher toll magnitude	S1
GP-Responsive Pricing Scenario (GP_RESP)	GP-density-responsive	Standard	Baseline	Effect of the congestion information source	S1
Reduced-Bound GP-Responsive Scenario (GP_RESP_LOW)	GP-density-responsive	0.70x	Baseline	Information source with milder tolls	S2_LOW
Reduced-Demand GP-Responsive Scenario (GP_RESP_D80)	GP-density-responsive	Standard	80% (92,927 veh)	Information source at low congestion	D80_ELController
Increased-Demand GP-Responsive Scenario (GP_RESP_D120)	GP-density-responsive	Standard	120% (139,391 veh)	Information source at high congestion	D120
80% Demand EL-Density Comparator (D80_ELController)	EL-density-responsive	Standard	80%	Matched comparator for GP_RESP_D80	-
120% Demand Scenario (D120)	EL-density-responsive	Standard	120%	Matched comparator for GP_RESP_D120 (Subtask 4.3 increased-demand scenario)	-

Source: Subtask 4.2 scenario definitions (Appendix R, Section R.2; Appendix S, Section S.2). Demand: requested vehicles over the 5,400-s simulation; the 80% and 120% levels scale every vehicle input. Standard toll bounds are the minimum and maximum toll rates of S1 for each level of service (LOS).

Terminology. The Express Lanes are the priced lanes and the GP lanes the unpriced lanes. A *toll decision point* is one of the 16 locations at which price-responsive single-occupant vehicles choose between the Express Lane route and the GP route; *toll transactions* count the tolled Express Lane choices, and the *EL share* is the share of vehicles at the toll decision points that choose the Express Lane route. *EL-density-responsive pricing* sets each segment toll from the measured Express Lane density; *GP-density-responsive pricing* (GP-responsive pricing) applies the same logic to measured GP-lane density. A *toll-bound sensitivity* scales the minimum and maximum toll rates of each LOS without changing the pricing logic. HGVs are trucks; in the study model they are excluded from the Express Lanes.

Common experimental design. All scenarios use the same network, vehicle compositions, routing and 12 random seeds, and every comparison is paired seed by seed. Each run simulates 5,400 s: a 1,800-s warm-up followed by a 3,600-s analysis hour, with tolls updated every 900 s. Toll transactions, EL share and revenue cover 0-4,500 s, the period priced by the toll updates; travel times, network delay and HGV results cover the analysis hour. A change is *statistically detectable* when the paired t-test and the exact Wilcoxon signed-rank test both give $p < 0.05$ (otherwise marked n.s.). It is *practically meaningful* when it also reaches the project's analytical screening thresholds: 2% for travel time and 5% for toll, transaction, share, revenue and volume measures and for network delay per vehicle. These thresholds are project-defined, not FDOT standards. The toll-bound technical analysis also applies a 10% threshold to section-level and Express Lane delay measures; those measures are not used here, and the S2_LOW and S2_HIGH network-delay changes are not statistically detectable, so the difference does not affect any conclusion.

Because HGVs do not use the Express Lanes (none was observed on any Express Lane detector, travel-time section or link in the S1, S2_LOW and S2_HIGH runs), freight effects are indirect. They are measured on the four GP travel-time sections, Sections 101 and 102 eastbound and Sections 201 and 202 westbound (Appendix R, Section R.10).

1.2 Reference Pricing Strategy (S1)

S1 represents the validated existing EL-density-responsive tolling framework of the study model and is the basis for every baseline comparison. Every 900 s the controller converts the Express Lane density on each of nine toll segments into an LOS (thresholds 11, 18, 26, 35 and 45 veh/mi/lane). It then sets the segment toll within LOS-specific minimum and maximum rates per mile, scaled by segment length and adjusted with a density-change table, applies a $0.25 segment minimum and rounds up to the next $0.05. A trip's toll is the sum of the segment tolls along its Express Lane route.

Under baseline demand the Express Lanes operate well below congestion. The Express Lane density read by the controller never exceeded LOS B (474 LOS A and 66 LOS B readings in 540 density-based segment updates; highest density 14.8 veh/mi/lane against the LOS C threshold of 18). Each segment toll therefore took at most two values, the LOS-A toll and one $0.05 step above

it. The density-change table altered the final toll in only 3.1% of updates, the mean segment toll was $0.61, and the highest tolls were $1.15 for a segment and $3.25 for a facility. Under these conditions S1 behaves as an almost fixed toll schedule whose level is set by the LOS bounds.

S1 establishes the benchmark values (12-seed means) against which all baseline-demand strategies are compared (Table 61):

- **Pricing and lane choice:** 3,160 toll transactions and $2,970 toll revenue per run (0-4,500 s), an average toll paid of $0.94, and an EL share of 18.4%.
- **Operations:** GP travel time of 1,152 s eastbound and 1,050 s westbound (sum of section means), Express Lane travel time of 554 s eastbound and 755 s westbound, and network delay of 100.1 s per vehicle.
- **Freight:** HGV mean travel time of 501 s to 622 s on the four GP sections.

Two questions follow from this behavior. If the toll level is set by the bounds, what happens when the bounds change (Section 1.3)? And if Express Lane density never signals congestion, what happens when the controller reads GP density instead (Section 1.4)?

1.3 Toll-Bound Sensitivities (S2_LOW and S2_HIGH)

The Reduced Toll-Bound Scenario (S2_LOW) multiplies every LOS-based minimum and maximum toll rate of S1 by 0.70, and the Increased Toll-Bound Scenario (S2_HIGH) multiplies them by 1.50. Nothing else changes: the controller logic, density thresholds, segment minimum, rounding, demand and routing are identical to S1. At LOS A, for example, the 7.6-mile Segment 4 is priced at $0.80, $1.15 and $1.75 under S2_LOW, S1 and S2_HIGH.

Lane choice and revenue. Toll magnitude had a strong and consistent effect (Table 61):

- S2_LOW changed the average toll paid by -23.5%, toll transactions by +8.9%, the EL share by +11.3% (from 18.4% to 20.5%) and revenue by -16.6%.
- S2_HIGH changed the average toll paid by +39.7%, toll transactions by -14.9%, the EL share by -18.3% (to 15.0%) and revenue by +18.9%.

Transactions, EL share and revenue moved in the same direction in all 12 seeds. Price-responsive demand was inelastic over the tested range: the approximate arc elasticity of transactions with respect to the average toll paid was -0.32 for the reduction and -0.48 for the increase. Revenue therefore followed the price: lower tolls attracted more Express Lane users but lost revenue, and higher tolls lost users but gained revenue.

Operations and freight. The same toll changes had little operational effect:

- The Express Lanes stayed uncongested in both scenarios (no toll update at LOS C or worse), and Express Lane section speeds changed by at most 0.4%.
- The passenger traffic shifted between the Express Lanes and the GP lanes was small relative to GP volume: GP single-occupant-vehicle volume per count station changed by at most 2.1%.

- GP travel time changed by +0.2% (n.s.) eastbound and -0.1% westbound under S2_LOW, and by +0.3% (n.s.) and +0.2% under S2_HIGH. Network delay per vehicle changed by -0.1% (n.s.) and +0.5% (n.s.).
- HGV mean travel time changed by at most 0.5% (S2_LOW) and 0.8% (S2_HIGH) on any GP section. Pooled hourly HGV 95th-percentile travel time and buffer index did not change significantly on any section (every seed-pair bootstrap 95% confidence interval included zero).

Toll magnitude is therefore an effective lever for lane choice and revenue but, under baseline demand, not for GP or freight operations: lower tolls did not produce a measurable indirect freight benefit, and higher tolls did not produce a measurable freight penalty. Detailed results are in Appendix R.

1.4 GP-Responsive Pricing Sensitivity

Motivation. The toll-bound sensitivities showed that toll magnitude moves lane choice and revenue but not operations, while S1 itself never sensed congestion because Express Lane density stayed at LOS A-B. The next question was therefore whether changing the congestion information used by the controller would make pricing operationally effective:

> *If changing toll magnitude strongly affects lane choice and revenue but produces limited operational effects, would setting the toll from GP congestion improve operational responsiveness, or would higher GP-triggered tolls discourage Express Lane use and leave additional vehicles in the congested GP lanes?*

Design. GP_RESP changes only the controller input, from Express Lane density to GP density measured by 296 single-lane detectors on the I-4 mainline through lanes at the existing Express Lane detector stations, so density stays in veh/mi/lane. The pricing mechanics of S1 (LOS thresholds, density-change table, toll bounds, segment minimum, rounding and update interval) are unchanged. GP-responsive pricing was tested as a sensitivity only; it is not a tolling policy in use or under consideration. A control simulation with the GP detectors installed but S1 pricing active reproduced S1 exactly, and every simulated toll was reproduced independently from the measured detector data.

Baseline result (GP_RESP vs S1). With GP density as its input the controller became far more active. GP density reached LOS C or D in 304 of 540 segment updates (56%); tolls were higher than in S1 in 400 of 540 (74%) segment updates and never lower; and Segment 4 reached its LOS-D ceiling of $4.30 in 10 of 12 seeds (S1 maximum $1.15). The stronger response again changed prices, lane choice and revenue rather than operations:

- **Pricing and lane choice:** the average toll paid changed by +22.9%, transactions by -11.2%, the EL share by -11.4% and revenue by +9.1%.
- **Operations:** GP travel time (+0.8% eastbound, +0.3% westbound) and network delay per vehicle (+1.0%) changed by statistically detectable but operationally small amounts.

- **Freight:** the effect was localized. Section 102 HGV mean travel time rose 1.5% and its pooled 95th-percentile travel time 3.0%, while both direction totals stayed below 2% (eastbound +0.8%, westbound +0.4%).

Under the pre-established rules the baseline comparison is classified as **not promising**.

Robustness testing. Three further comparisons tested whether the baseline result depended on toll level or demand (Table 62 in Section 1.5):

- **Reduced toll bounds (GP_RESP_LOW vs S2_LOW).** The 0.70x bounds moderated the GP-responsive tolls (maximum segment toll $3.00 instead of $4.30). Against S2_LOW, which uses the same bounds with Express Lane density, GP_RESP_LOW still raised the average toll by 23.3% and revenue by 14.2% and changed transactions by -7.4%. It produced no operational or freight benefit: GP travel time, network delay per vehicle and HGV travel time changed by at most 0.5%. Classification: **operationally neutral**; GP_RESP_LOW functioned as a higher-priced alternative to S2_LOW.
- **80% demand (GP_RESP_D80 vs D80_ELController).** The GP-responsive controller priced above the LOS-A level in 328 of 540 segment updates (61%), against 0 of 540 for the comparator. There was little congestion to manage: GP travel time, network delay per vehicle and HGV travel time changed by at most 0.2%. Classification: **operationally neutral**.
- **120% demand (GP_RESP_D120 vs D120).** GP density reached LOS E or F in 44 of 540 segment updates (8%). The highest tolls reached $7.50 per segment and $15.40 per facility, against $1.15 and $3.25 for D120. Transactions fell 26.5% and the EL share 23.8%; GP density rose 7.3% eastbound and 4.6% westbound, so more vehicles remained in the GP lanes. Westbound GP travel time rose 3.8% and network delay per vehicle 6.8%, both above the practical thresholds (eastbound GP travel time +1.3%), while revenue rose only 4.3%. HGV results differed by section (Section 102 -4.4%, Section 101 +3.2%, Section 201 +7.2%), so under the pre-established section-level rule the comparison is classified as **mixed-tradeoff**. As supplementary interpretation only, the corridor totals from the same runs show westbound HGV travel time +3.6% and eastbound -0.3% (n.s.), so the Section 102 gain was not a corridor benefit; this supplementary assessment does not replace the pre-established classification.

Mechanism. The controller responded as intended; the lack of benefit was not caused by an inactive controller. The behavioral response to higher GP-triggered tolls, with fewer Express Lane users and more vehicles in the GP lanes, worked against the congestion-management objective. This feedback was present in every comparison but remained weak, with no toll oscillation and no throughput instability.

Finding. The four comparisons keep their individual classifications: not promising at baseline demand, operationally neutral with reduced bounds and at 80% demand, and mixed-tradeoff at 120% demand. Taken together:

Overall GP-responsive finding: no demonstrated operational advantage; no further testing of the current GP-responsive formulation is recommended.

The complete GP-responsive analysis, including validation, seed-level statistics, LOS distributions, controller diagnostics and section-level freight results, is preserved unchanged in Appendix S.

1.5 Comparative Pricing Strategy Assessment

Table 61 compares the four baseline-demand alternatives with S1. Table 62 compares each GP-responsive scenario with its matched EL-density-responsive comparator. Figures 102 and 103 show both sets of comparisons, separating the lane-choice and revenue response from the operational response.

Table 61. Master Pricing-Strategy Comparison at Baseline Demand (Change Relative to the Reference Pricing Strategy, S1)

Scenario	Pricing concept	Comparator	Toll transactions	EL share	Average toll paid	Toll revenue	GP operational effect	Freight effect	Overall interpretation
Reference Pricing Strategy (S1)	EL-density-responsive; standard bounds	Reference values	3,160 per run	18.4%	$0.94	$2,970 per run	GP travel time 1,152 s EB, 1,050 s WB; network delay 100.1 s per vehicle	HGV mean travel time 501-622 s by GP section	Benchmark: Express Lanes at LOS A-B; toll level set by the LOS bounds
Reduced Toll-Bound Scenario (S2_LOW)	EL-density-responsive; 0.70x bounds	S1	+8.9%	+11.3%	-23.5%	-16.6%	Negligible: GP travel time +0.2% (n.s.) EB, -0.1% WB; network delay -0.1% (n.s.)	No measurable effect: HGV within 0.5% on every section; no significant reliability change	More Express Lane use, less revenue; no operational effect
Increased Toll-Bound Scenario (S2_HIGH)	EL-density-responsive; 1.50x bounds	S1	-14.9%	-18.3%	+39.7%	+18.9%	Negligible: GP travel time +0.3% (n.s.) EB, +0.2% WB; network delay +0.5% (n.s.)	No measurable effect: HGV within 0.8% on every section; no significant reliability change	Less Express Lane use, more revenue; no operational effect

Table 61. Master Pricing-Strategy Comparison at Baseline Demand (Change Relative to the Reference Pricing Strategy, S1) (continued)

Scenario	Pricing concept	Comparator	Toll transactions	EL share	Average toll paid	Toll revenue	GP operational effect	Freight effect	Overall interpretation
GP-Responsive Pricing Scenario (GP_RESP)	GP-density-responsive; standard bounds	S1	-11.2%	-11.4%	+22.9%	+9.1%	Small adverse: GP travel time +0.8% EB, +0.3% WB; network delay +1.0%	Localized deterioration: Section 102 HGV mean +1.5%, 95th percentile +3.0%	Not promising (individual classification): higher tolls and revenue, fewer Express Lane users, no operational benefit
Reduced-Bound GP-Responsive Scenario (GP_RESP_LOW)	GP-density-responsive; 0.70x bounds	S1 (matched comparator S2_LOW: Table 62)	+0.9%	+2.8%	-5.7%	-4.8%	Negligible: GP travel time +0.3% (n.s.) EB, +0.1% WB; network delay +0.4% (n.s.)	No measurable effect: HGV within 0.6% (n.s.) on every section	Pricing outcome close to S1; operationally neutral against its matched comparator S2_LOW

Source: Subtask 4.2 paired 12-seed analyses; detailed statistics in Appendix R (S2_LOW, S2_HIGH) and Appendix S (GP_RESP, GP_RESP_LOW). Percent changes are paired 12-seed mean differences relative to S1; S1 shows 12-seed means. n.s. = not statistically detectable (paired t-test or exact Wilcoxon signed-rank test p >= 0.05). Transactions, EL share, toll and revenue cover 0-4,500 s; travel times, network delay and HGV results cover the 1,800-5,400 s analysis hour. GP travel time is the sum of the GP section mean travel times per direction. Practical thresholds: 2% for travel time; 5% for pricing, lane-choice and volume measures and for network delay per vehicle.

Table 62. GP-Responsive Robustness Assessment (GP Density versus EL Density, Paired with the Matched Comparator)

Test condition	GP-responsive scenario vs matched comparator	Pricing response	Operational response	Freight response	Classification (pre-established rules)
Reduced toll bounds	GP_RESP_LOW vs S2_LOW	Average toll +23.3%; transactions -7.4%; EL share -7.6%; revenue +14.2%	GP travel time +0.1% (n.s.) EB, +0.2% WB; network delay +0.5%	No measurable effect (all sections within 0.4%)	Operationally neutral
80% demand	GP_RESP_D80 vs D80_ELController	Average toll +11.5%; transactions -4.9%; EL share -5.2%; revenue +6.0%	GP travel time 0.0% (n.s.) EB, +0.1% WB; network delay +0.1% (n.s.)	No measurable effect (all sections within 0.2%)	Operationally neutral
Baseline demand	GP_RESP vs S1	Average toll +22.9%; transactions -11.2%; EL share -11.4%; revenue +9.1%	GP travel time +0.8% EB, +0.3% WB; network delay +1.0%	Localized: Section 102 HGV mean +1.5%, 95th percentile +3.0%	Not promising

Table 62. GP-Responsive Robustness Assessment (GP Density versus EL Density, Paired with the Matched Comparator) (continued)

Test condition	GP-responsive scenario vs matched comparator	Pricing response	Operational response	Freight response	Classification (pre-established rules)
120% demand	GP_RESP_D120 vs D120	Average toll +42.0%; transactions -26.5%; EL share -23.8%; revenue +4.3%	GP travel time +1.3% EB, +3.8% WB; network delay +6.8%	Mixed by section: Section 102 -4.4%, Section 101 +3.2%, Section 201 +7.2%; supplementary corridor totals: WB +3.6%, EB -0.3% (n.s.)	Mixed-tradeoff

Source: GP-responsive paired 12-seed analyses; detailed statistics in Appendix S (Sections S.C and S.G). Percent changes are paired 12-seed mean differences relative to the matched EL-density-responsive comparator. n.s. = not statistically detectable (paired t-test or exact Wilcoxon signed-rank test p >= 0.05). The corridor totals at 120% demand are supplementary evidence and do not replace the pre-established section-level classification. Overall finding: no demonstrated operational advantage; no further testing of the current GP-responsive formulation is recommended.

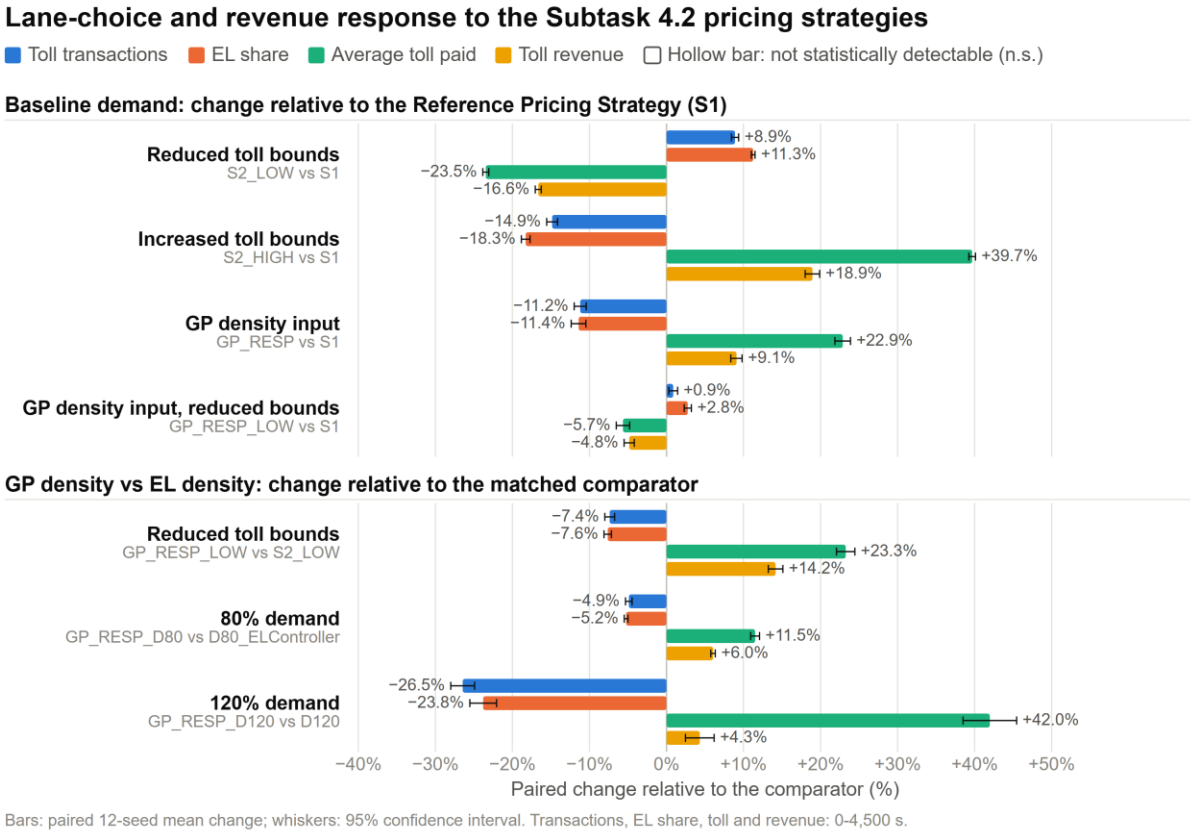


Figure 102. Lane-Choice and Revenue Response to the Subtask 4.2 Pricing Strategies

Source: Subtask 4.2 paired 12-seed analyses (Appendices R and S). Every strategy that changed the toll level changed toll transactions, EL share and revenue substantially (at baseline demand between -23.5% and +39.7% in the average toll paid). GP

density as the controller input moved the toll, transactions and EL share in the same direction as higher toll bounds, more strongly as demand increased.

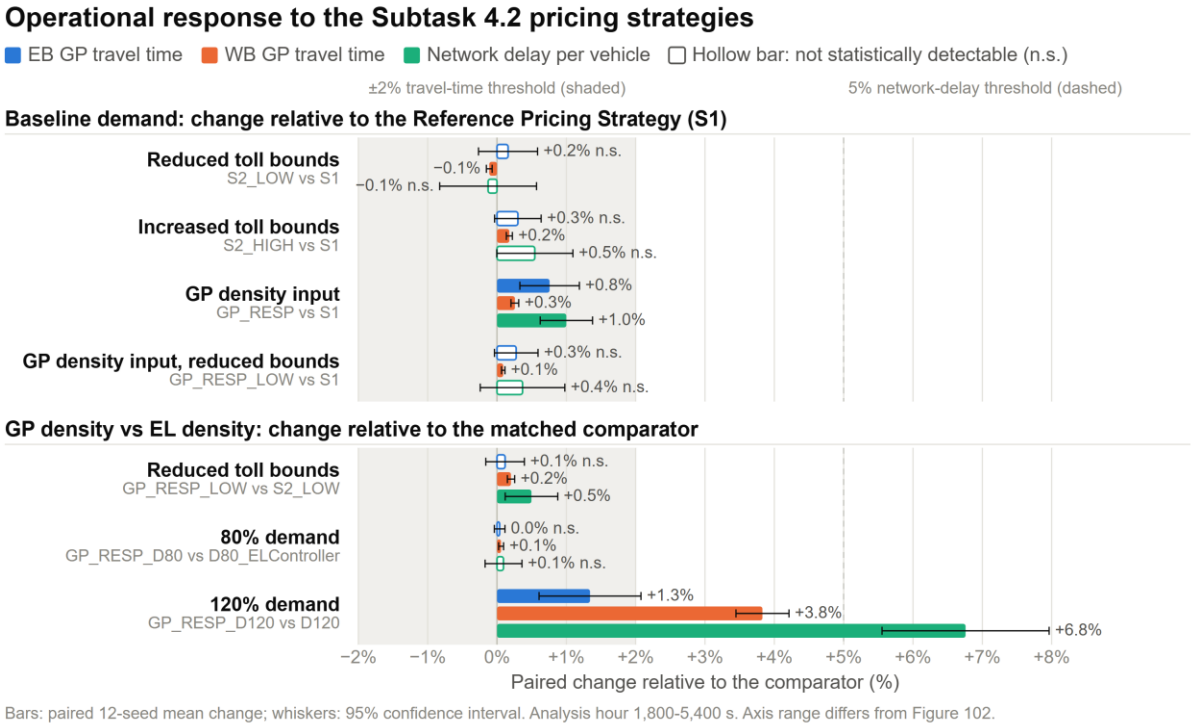


Figure 103. Operational Response to the Subtask 4.2 Pricing Strategies

Source: Subtask 4.2 paired 12-seed analyses (Appendices R and S). At baseline demand no strategy changed GP travel time by more than 0.8% or network delay per vehicle by more than 1.0%. Only the GP-responsive strategy at 120% demand exceeded a practical threshold, in the adverse direction (WB GP travel time +3.8%, network delay per vehicle +6.8%). The x-axis spans -2% to +8%, against -40% to +50% in Figure 102.

Financial and behavioral response versus operational response. The evidence separates two kinds of response.

- *Financial and behavioral response (toll level, toll transactions, EL share, revenue).* Every strategy that changed the toll level changed lane choice and revenue substantially and consistently. At baseline demand the average toll paid ranged from -23.5% (S2_LOW) to +39.7% (S2_HIGH) relative to S1, toll transactions from -14.9% to +8.9%, the EL share from -18.3% to +11.3%, and revenue from -16.6% to +18.9%; every one of these changes was statistically detectable.
- *Operational response (GP and Express Lane travel time, network delay, freight).* At baseline demand no alternative changed GP travel time by more than 0.8%, Express Lane travel time by more than 0.4% or network delay per vehicle by more than 1.0%, and no HGV mean travel time changed by more than 1.5% on any section. The only freight change above 2% was the localized increase in the Section 102 95th-percentile travel time under GP_RESP (+3.0%).

For S2_LOW, S2_HIGH and GP_RESP, the smallest change in any pricing or lane-choice measure (8.9%) was larger than the largest change in GP travel time or network delay (1.0%) by nearly an order of magnitude. Pricing acted on who used the Express Lanes and what they paid, not on how the corridor operated.

Pricing magnitude and information source compared. S2_HIGH and GP_RESP both raised tolls and reduced Express Lane use. GP_RESP raised the average toll by less than S2_HIGH (+22.9% against +39.7%), and its revenue gain was correspondingly smaller (+9.1% against +18.9%), but its loss of transactions was of similar size (-11.2% against -14.9%). It was also the only baseline alternative with statistically detectable increases in GP travel time in both directions and in network delay per vehicle. Combining GP density with the reduced bounds (GP_RESP_LOW) produced pricing outcomes close to S1 (transactions +0.9%, EL share +2.8%, average toll -5.7%, revenue -4.8%) and again no operational benefit (GP travel time +0.3% (n.s.) eastbound and +0.1% westbound; network delay +0.4% (n.s.)). Changing the information source altered when and by how much the toll rose, but it did not create an operational effect that the simpler toll-bound changes lacked.

Demand dependence. The operational effect of the GP-responsive formulation did not improve with congestion. Relative to the matched comparators, network delay per vehicle changed by +0.1%, +1.0% and +6.8% at 80%, 100% and 120% demand, and the EL share by -5.2%, -11.4% and -23.8% (Figures 102 and 103). The controller charged more as congestion increased, which moved more vehicles out of the Express Lanes when GP capacity was scarcest.

1.6 Freight and Operational Implications

HGVs do not use the Express Lanes, so pricing can affect freight only indirectly, through the passenger traffic it shifts between the Express Lanes and the GP lanes. The freight evidence is consistent across all experiments:

- **Toll-bound sensitivities (S2_LOW, S2_HIGH): little freight effect.** HGV mean travel time changed by at most 0.5% and 0.8% on any section, and pooled hourly HGV reliability did not change significantly. The small, statistically detectable reductions under S2_LOW (-0.3% on Sections 101 and 201) were far below the 2% threshold.
- **Baseline GP-responsive pricing (GP_RESP): localized freight deterioration** on Section 102 (mean travel time +1.5%, 95th percentile +3.0%), with both direction totals below 2%.
- **Reduced bounds and 80% demand (GP_RESP_LOW, GP_RESP_D80): no measurable freight advantage** (all sections within 0.4% and 0.2% of their comparators).
- **120% demand (GP_RESP_D120): mixed section-level results** (-4.4% to +7.2%), with supplementary corridor evidence of adverse westbound performance (+3.6%).

No pricing strategy evaluated in Subtask 4.2 demonstrated a practically meaningful freight operational benefit.

The operational evidence points to two mechanisms:

- **Uncongested Express Lanes limit what toll magnitude can do.** Under baseline demand the Express Lanes remained at LOS A-B in S1, S2_LOW and S2_HIGH, so adding or removing price-responsive vehicles changed Express Lane density but not Express Lane speed. The volume shifted to or from the GP lanes was too small to change GP travel time materially.
- **A GP-triggered toll pushes traffic toward the congested lanes.** When the toll responded to GP congestion, vehicles leaving the Express Lanes added to GP traffic. At 120% demand this outweighed the small gain for the remaining Express Lane users (Express Lane travel time -1.4% eastbound, -0.7% westbound), and westbound GP travel time and network delay increased. The revenue gains of GP-responsive pricing came from higher tolls on fewer trips, not from better service.

1.7 Limitations

The findings are simulation-based sensitivity results for the modeled I-4 corridor under 2040 PM-peak demand and network conditions and should not be generalized to other corridors or demand conditions without further analysis. Under baseline demand the Express Lanes never approached congestion, so the EL-density-responsive controller was only weakly dynamic and the toll-bound results reflect that regime. Every strategy reuses the existing controller framework of the study model: the GP-responsive scenarios apply the EL-oriented LOS thresholds, density-change table, toll bounds, segment minimum and 15-minute update interval to GP density without re-deriving them, and no strategy was optimized for revenue, operations or policy constraints on toll levels. Driver response to the new pricing concepts relies on the route-choice behavior of the validated model; no independent willingness-to-pay calibration was carried out for tolls well above the S1 range (S1 maximum segment toll $1.15; GP_RESP_D120 maximum $7.50), and the price elasticities are approximate. The tested GP-responsive formulation is one way of using GP density and does not represent all possible GP-responsive tolling strategies; the results show only that this formulation did not provide an operational advantage. At 120% demand the 5,400-s horizon was only partially sufficient: GP density peaked in the final, unpriced 15 minutes in 45 of 108 seed-segments, and the westbound GP travel-time effect grew in every analysis interval (+0.1%, +1.6%, +3.8% and +8.1%) rather than reversing, which limits interpretation of the late period.

1.8 Conclusions and Recommendations

1. Did changing toll magnitude affect lane choice? Yes. Toll magnitude is a strong and reliable lever on lane choice: lower bounds drew price-responsive drivers into the Express Lanes (transactions +8.9%), higher bounds pushed them out (-14.9%), and the direction of the change held in every seed.

2. Did changing toll magnitude affect revenue? Yes, in the direction of the price. Price-responsive demand was inelastic (approximate elasticities -0.32 and -0.48), so the change in the toll outweighed the change in transactions: revenue -16.6% with lower bounds and +18.9% with

higher bounds. Express Lane use and revenue therefore trade off against each other; neither bound level improves both.

3. Did changing toll magnitude materially improve GP operations? No. The Express Lanes stayed uncongested, and the volume shifted between the Express Lanes and the GP lanes was small relative to GP volume, so GP travel time and network delay per vehicle changed by less than 1% and HGV mean travel time by at most 0.8%.

4. Did GP-responsive pricing create a stronger controller response? Yes. GP density signals congestion far more often than Express Lane density, so the same controller changed from an almost fixed toll schedule into an actively responsive one: tolls exceeded S1 in 400 of 540 (74%) segment updates and, at 120% demand, reached $7.50 per segment and $15.40 per facility.

5. Did that stronger response improve operations or freight? No. The stronger response worked through the same lane-choice mechanism as a toll increase: higher tolls moved vehicles out of the Express Lanes and into the GP lanes. That offset any benefit with reduced bounds and at 80% and baseline demand, and outweighed it at 120% demand (westbound GP travel time +3.8%, network delay per vehicle +6.8%). Freight effects were localized, negligible or mixed, never a corridor-level benefit.

6. What does this imply for future operational strategy development? Within the modeled conditions, the toll level and the toll trigger act mainly on who uses the Express Lanes and what they pay. Pricing strategies are therefore best assessed against lane-choice, revenue and Express Lane performance objectives. Objectives for GP or freight performance would need mechanisms that act on GP-lane conditions directly, rather than through the toll level alone. A GP-congestion trigger is not by itself such a mechanism, because the behavioral response to a higher toll is to leave the Express Lanes.

Conclusion. The pricing sensitivity analysis demonstrated that Express Lane toll strategies strongly influence Express Lane utilization and revenue but produced comparatively limited changes in corridor operations under the tested baseline conditions. Reduced toll bounds increased Express Lane use while reducing revenue, whereas increased toll bounds reduced Express Lane use and increased revenue. Replacing Express Lane density with GP density substantially increased controller activity and toll responsiveness, but this stronger response did not yield a consistent operational or freight advantage. Under elevated demand, the GP-responsive strategy reduced Express Lane utilization and was associated with higher GP travel time and network delay. These findings indicate that pricing adjustments alone may be more effective as lane-choice and revenue-management tools than as mechanisms for materially improving corridor or freight operations within the modeled conditions.

Recommendations.

- **Toll-bound sensitivities (S2_LOW, S2_HIGH):** retain as sensitivity evidence that quantifies the lane-choice and revenue tradeoff of the toll level. They are sensitivity

experiments, not proposed toll policies; the analysis does not recommend adopting either bound level.

- **GP-responsive pricing:** no demonstrated operational advantage; no further testing of the current GP-responsive formulation is recommended. The GP-responsive analysis is final; additional VISSIM runs of the current formulation are not recommended unless the FDOT project team reopens the analysis.
- These results do not show that Express Lane pricing is ineffective, or that GP-responsive tolling concepts in general cannot work. They show that, in the modeled conditions, the tested pricing changes acted on lane choice and revenue rather than on corridor or freight operations.

The expanded GP-responsive sensitivity analysis helps eliminate a technically feasible but operationally unproductive formulation from further consideration within this study, allowing modeling and implementation resources to be directed toward more promising strategies.

Supporting technical material. Appendix R contains the complete toll-bound sensitivity analysis of S1, S2_LOW and S2_HIGH (scenario configuration, validation, paired statistics, Express Lane and GP operations, freight reliability and toll behavior by segment). Appendix S contains the frozen GP-responsive pricing sensitivity (full section, technical appendix and freeze note).

2 Future Demand Scenarios

2.1 Objective and Scenario Development

This subtask examines how the modeled I-4 corridor responds when travel demand grows beyond the 2040 PM-peak baseline. The research question is:

> *How does increasing corridor demand affect GP operations, Express Lane performance, freight conditions, and the response of the existing EL-density-responsive pricing controller?*

Four demand levels were simulated (Table 63):

- Baseline Demand (S1);
- 110% Demand Scenario (D110);
- 120% Demand Scenario (D120);
- 130% Demand Scenario (D130).

S1 is the same set of runs that Subtask 4.2 uses as its Reference Pricing Strategy (Chapter 1). D120 also serves as the matched comparator for the increased-demand GP-responsive pricing sensitivity (Section 1.4).

The three increments are **controlled demand-growth sensitivity scenarios**, not forecasts for specific future years. Every vehicle input is scaled uniformly above the 2040 baseline. The trip pattern, vehicle mix, network and pricing policy are unchanged, so differences between scenarios isolate the effect of more demand.

Terminology follows Subtask 4.2 (Section 1.1):

- the Express Lanes are the priced lanes and the GP lanes the unpriced lanes;
- HGVs are trucks, which in the study model do not use the Express Lanes;
- the EL share is the share of price-responsive single-occupant vehicles at the 16 toll decision points that choose the Express Lane route.

2.2 Demand Scaling and Experimental Design

Demand scaling. All 330 vehicle-input volumes of the S1 model (66 inputs x 5 time intervals) were multiplied by exactly 1.10, 1.20 and 1.30. Requested demand over the 5,400-s simulation rises from 116,159 vehicles to 127,775, 139,391 and 151,007. The HGV share of requested demand stays at 2.4%.

Everything else is identical to S1:

- input locations, temporal profile and vehicle compositions;
- static routing and the route choice at the toll decision points;
- geometry, signals, driving behavior and the HGV lane restrictions;

- the complete toll controller.

The controller sets each segment toll every 900 s from the measured Express Lane density. It uses LOS thresholds of 11, 18, 26, 35 and 45 veh/mi/lane, LOS-specific toll bounds and a density-change table, applies a $0.25 minimum and rounds up to $0.05.

Experimental design. Every scenario was simulated with the same 12 random seeds, and each scenario is compared with S1 seed by seed. Each run covers 5,400 s: a 1,800-s warm-up and a 3,600-s analysis hour. Toll transactions, EL share and revenue cover 0-4,500 s, the period priced by the toll updates.

All 48 paired runs reached 5,400 s with complete outputs and no errors. Two runs outside the paired set were excluded:

- a duplicate S1 check run;
- an earlier, incomplete D130 attempt that stopped at 3,035.7 s, replaced by the complete run of the same seed.

Further validation:

- every one of the 7,200 simulated tolls was reproduced from the measured detector data;
- no HGV was observed in the Express Lanes in any run;
- the non-fatal VISSIM warnings that rise with demand (inputs that cannot load all their vehicles, lane-change removals) are consistent with heavier loading, not with model failure.

A change is **statistically detectable** when the paired t-test and the exact Wilcoxon signed-rank test both give $p < 0.05$. Practical thresholds follow Subtask 4.2: 2% for travel time and 5% for network delay per vehicle. The Subtask 4.3 technical files apply 10% to delay measures; no conclusion depends on the difference. Confidence intervals and seed-level results are in Appendix T.

2.3 Demand Loading and Network Entry

Table 63. Future Demand Scenario Loading Summary

Scenario	Requested vehicles, 0-5,400 s	Requested increase	Realized (inserted) vehicles	Realized increase vs S1	Unserved vehicles	Unserved, % of requested
Baseline Demand (S1)	116,159	-	115,158	-	1,001	0.86%
110% Demand Scenario (D110)	127,775	+10.0%	126,179	+9.57%	1,596	1.25%
120% Demand Scenario (D120)	139,391	+20.0%	136,774	+18.77%	2,617	1.88%
130% Demand Scenario (D130)	151,007	+30.0%	146,097	+26.87%	4,910	3.25%

Source: Subtask 4.3 paired 12-seed analysis; confidence intervals and entry-point detail in Appendix T (Section T.3). 12-seed means. Requested demand is the sum of the scaled vehicle-input volumes over the 5,400-s simulation; realized vehicles are those inserted into the network; unserved vehicles could not enter before the end of the simulation.

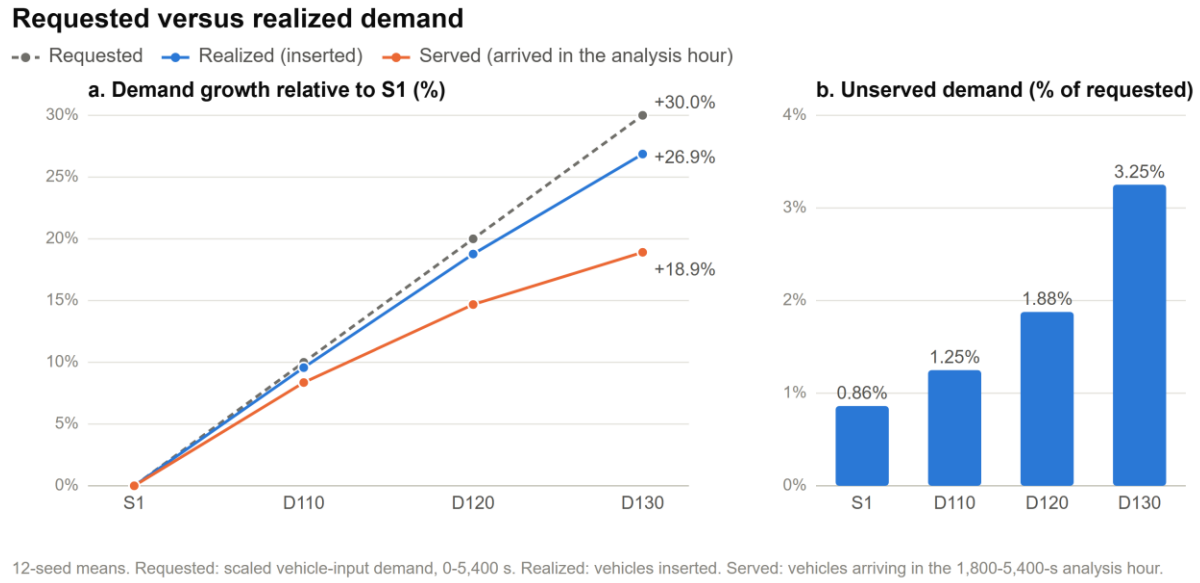


Figure 104. Requested versus Realized Demand

Source: Subtask 4.3 paired 12-seed analysis (Appendix T, Section T.3). Requested demand rises by exactly 10%, 20% and 30%, but realized demand rises by 9.6%, 18.8% and 26.9%, and unserved demand grows from 0.86% to 3.25% of requested. The gap widens with each step as more entry points reach capacity.

Realized demand grows less than requested demand, and the gap widens (Figure 104). Requested demand rises by exactly 10%, 20% and 30%. The number of vehicles that actually entered the network rose by 9.57%, 18.77% and 26.87% (95% confidence intervals 9.52-9.62%, 18.71-18.83% and 26.75-26.98%). Unserved demand rose from 0.86% of requested demand in S1 to 1.25%, 1.88% and 3.25%.

VISSIM inserts a vehicle only when there is room on the entry link:

- In S1, three arterial inputs already leave about 1,000 vehicles per run unserved.
- Each 10% step adds the same 11,616 requested vehicles, but a smaller share of them can enter: 94.9%, 91.2% and 80.3% in the three successive steps.
- The constraint also spreads. New entry points with unserved demand appear at D110 (2), D120 (11) and D130 (19).
- At D130 both I-4 mainline entries leave vehicles unserved: on average 214 vehicles at one entry (12 of 12 seeds) and 41 at the other (10 of 12 seeds).
- Served demand, the vehicles arriving during the analysis hour, grows even less (8.4%, 14.7% and 18.9%), because more vehicles are still in the network when the simulation ends.

D130 is a valid high-demand stress scenario, not a simulation failure. None of the loading-failure criteria is met:

- unserved demand is 3.25% of requested (limit 5%);
- 11.2% of the added requested demand is unserved (limit 50%);
- the lowest GP section mean speed is 45.6 mph (limit 30 mph);
- all outputs are complete.

D130 is, however, clearly constrained by capacity and loading. It should be read as the upper bound of the tested range, together with its unserved demand. All results in this section describe realized demand.

2.4 GP and Express Lane Operational Effects

Table 64. Operational Effects (Change Relative to S1, 12 Paired Seeds)

Measure	S1	D110	D120	D130
GP travel time, EB (Sections 101+102)	1,152 s	+8.2%	+22.3%	+32.0%
GP travel time, WB (Sections 201+202)	1,050 s	+1.6%	+8.6%	+14.9%
Network delay per vehicle	100.1 s	+26.2%	+78.7%	+149.1%
Network vehicles arrived (served demand)	80,031	+8.4%	+14.7%	+18.9%
GP throughput, EB (Sections 101+102, veh-sections/h)	2,655	+2.6%	+1.3% (n.s.)	-2.4%
EL travel time, EB / WB	554 s / 755 s	+0.7% / +0.1% (n.s.)	+1.6% / +0.3%	+2.7% / +0.5%
EL space-mean speed, EB / WB	67.2 mph / 70.6 mph	-0.8% / -0.1% (n.s.)	-1.9% / -0.4%	-3.5% / -0.5%
EL throughput, EB / WB (veh-sections/h)	4,984 / 3,601	+14.9% / +9.7%	+32.3% / +21.5%	+51.3% / +31.3%

Source: Subtask 4.3 paired 12-seed analysis (Appendix T, Section T.4). Paired 12-seed mean changes relative to S1, rounded once from full precision; (n.s.) = not statistically detectable (paired t-test and exact Wilcoxon signed-rank test do not both give $p < 0.05$). Analysis hour 1,800-5,400 s. 95% confidence intervals and seed-level results: Appendix T.

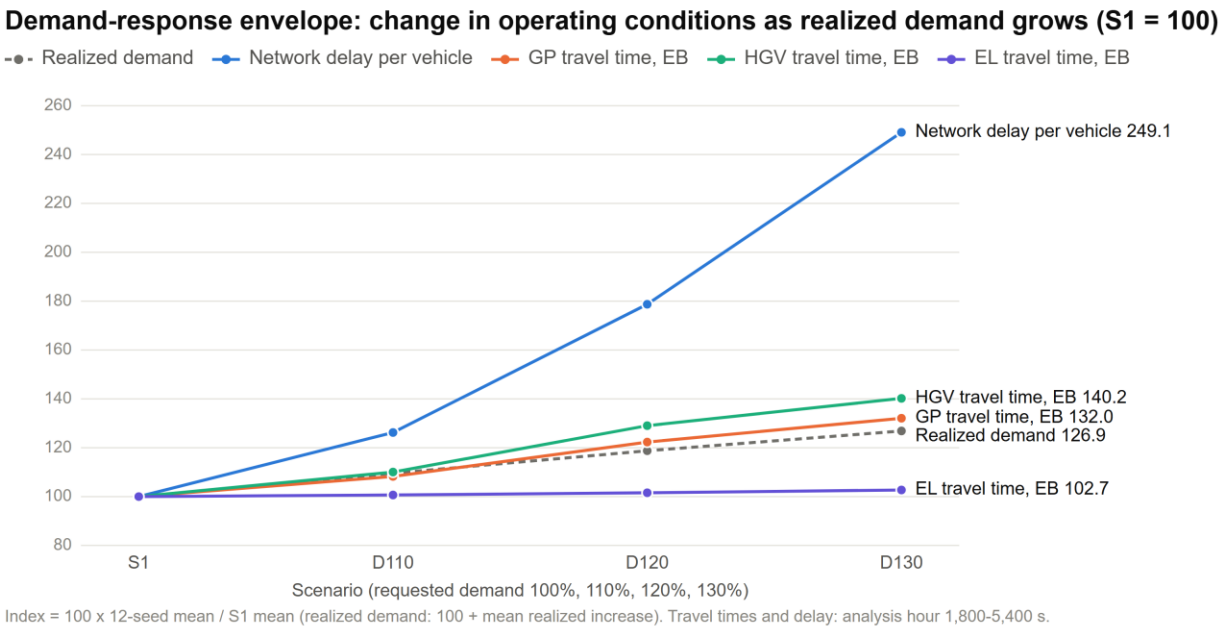


Figure 105. Demand-Response Envelope (S1 = 100)

Source: Subtask 4.3 paired 12-seed analysis (Appendix T, Section T.4). Network delay per vehicle grows 2.7, 4.2 and 5.5 times as fast as realized demand. Eastbound freight travel time outpaces demand at every level and eastbound GP travel time from D120, while eastbound Express Lane travel time stays within 2.7% of S1.

GP and network performance degrade disproportionately (Table 64).

- Eastbound GP travel time increased by 8.2%, 22.3% and 32.0%, and westbound by 1.6%, 8.6% and 14.9%.
- Network delay per vehicle increased by 26.2%, 78.7% and 149.1%.
- Every one of these changes is statistically detectable and occurred in all 12 seeds.

The response is strongly nonlinear. Relative to the realized demand increase, network delay per vehicle grew 2.7, 4.2 and 5.5 times as fast. Eastbound GP travel time grew more slowly than demand at D110 (0.9 times) but about 1.2 times as fast at both D120 and D130, as the eastbound GP sections reached capacity. Eastbound GP throughput first rose (+2.6%), then leveled off (+1.3%, not statistically detectable), and at D130 fell below S1 (-2.4%).

Express Lane performance remains comparatively stable.

- EL space-mean speed changed by at most 3.5% (eastbound, D130).
- Eastbound EL travel time increased by only 0.7%, 1.6% and 2.7%.
- Over the same range the Express Lanes carried substantially more traffic: eastbound EL throughput +14.9%, +32.3% and +51.3%.

The contrast between the two facilities widens with every demand step (Figure 105).

2.5 Freight/HGV Effects

Table 65. Freight (HGV) Effects on the GP Lanes (Change Relative to S1, 12 Paired Seeds)

Measure	S1	D110	D120	D130
HGV mean travel time, EB (Sections 101+102)	1,197 s	+10.0%	+29.0%	+40.2%
HGV mean travel time, WB (Sections 201+202)	1,080 s	+3.0%	+13.2%	+23.4%
Network delay per HGV	111.4 s	+28.9%	+92.4%	+171.2%
HGV 95th-percentile travel time, Section 101	670 s	755 s (+12.6%)	1,184 s (+76.7%)	1,349 s (+101.3%)
HGV 95th-percentile travel time, Section 102	649 s	853 s (+31.4%)	947 s (+45.9%)	1,013 s (+56.1%)
HGV 95th-percentile travel time, Section 201	530 s	540 s (+2.0%)	692 s (+30.7%)	872 s (+64.6%)
HGV 95th-percentile travel time, Section 202	613 s	682 s (+11.3%)	843 s (+37.6%)	939 s (+53.2%)

Source: Subtask 4.3 paired 12-seed analysis (Appendix T, Sections T.4 and T.8). Paired 12-seed mean changes relative to S1, rounded once from full precision; (n.s.) = not statistically detectable (paired t-test and exact Wilcoxon signed-rank test do not both give $p < 0.05$). Analysis hour 1,800-5,400 s. 95% confidence intervals and seed-level results: Appendix T. Directional HGV travel time is the sum of the section mean HGV travel times. 95th-percentile values pool the raw HGV records of the 12 seeds for the analysis hour; every change shown is significant (seed-pair bootstrap 95% confidence interval excludes zero).

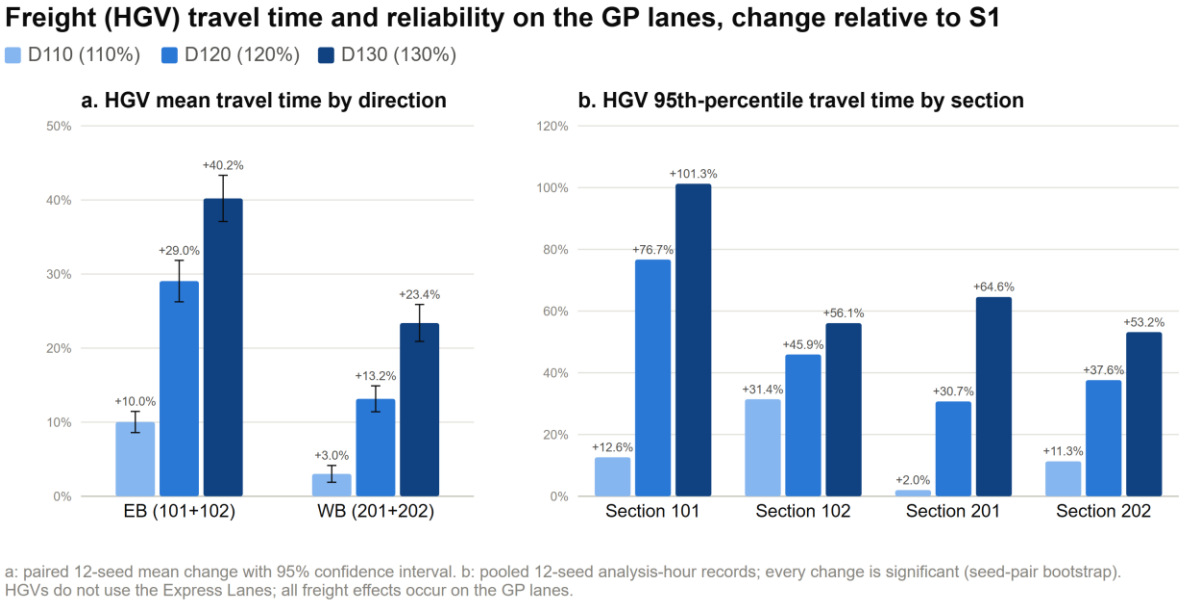


Figure 106. Freight (HGV) Effects on the GP Lanes

Source: Subtask 4.3 paired 12-seed analysis (Appendix T, Sections T.4 and T.8). Truck travel time and its 95th percentile increase in both directions and on every section at every demand level (D130: eastbound +40.2%, westbound +23.4%), although HGVs do not use the Express Lanes.

Freight conditions deteriorate as passenger demand grows, even though HGVs remain in the GP lanes and do not use the Express Lanes (Table 65 and Figure 106).

- Mean HGV travel time rose by 10.0%, 29.0% and 40.2% eastbound, and by 3.0%, 13.2% and 23.4% westbound.
- Network delay per HGV rose by 28.9%, 92.4% and 171.2%, more than network delay per vehicle overall at every level.
- Reliability deteriorated with the means. The pooled 95th-percentile HGV travel time increased on every section at every level, for example on Section 102 from 649 s in S1 to 853 s (+31.4%), 947 s (+45.9%) and 1,013 s (+56.1%).

The pattern is broad rather than local. Every directional and section-level change in mean HGV travel time is statistically detectable and occurred in all 12 seeds. Eastbound freight is affected first and most, consistent with the eastbound GP capacity constraint; westbound freight deteriorates mainly from D120.

2.6 Pricing and Controller Response

Table 66. Express Lane Density and Pricing-Controller Response (12 Paired Seeds)

Measure	S1	D110	D120	D130
Highest 15-minute EL density, any seed (veh/mi/lane)	14.8	18.5	23.0	29.8
Seeds with EL LOS C or worse in any 15-minute interval (of 12)	0	1	12	12
Seeds with EL LOS C or worse at a toll update (of 12)	0	0	8	12
Toll updates at LOS C or worse (of 540)	0	0	8	27
Toll updates at the segment LOS-A toll (% of 540)	96.1%	90.6%	85.7%	81.1%
Toll changes larger than $0.05 (of 540)	0	0	0	9
Average toll paid per transaction	$0.94	+0.9%	+2.7%	+5.0%
Toll transactions, 0-4,500 s	3,160	+11.3%	+22.9%	+37.7%
Toll revenue, 0-4,500 s (share of the change from higher tolls)	$2,970	+12.4% (4.1%)	+26.2% (3.9%)	+44.6% (5.2%)

Table 66. Express Lane Density and Pricing-Controller Response (12 Paired Seeds) (continued)

Measure	S1	D110	D120	D130
EL share at the toll decision points	18.4%	+2.2%	+5.7%	+11.1%
Pooled controller classification	effectively fixed	weakly dynamic	weakly dynamic	weakly dynamic

Source: Subtask 4.3 paired 12-seed analysis (Appendix T, Sections T.4, T.9 and T.11). Controller rows pool the 540 density-based toll updates of each level (9 segments x 5 updates at 900-4,500 s x 12 seeds). "Any 15-minute interval" includes the final interval (4,500-5,400 s), which no toll update reads. Average toll, transactions, revenue and EL share: paired 12-seed changes relative to S1, 0-4,500 s. The share in brackets is the part of the revenue change caused by higher tolls rather than by more transactions at the S1 tolls. "Weakly dynamic": tolls move between level-of-service bound values, with no material interior pricing. The pricing policy is identical in all four scenarios.

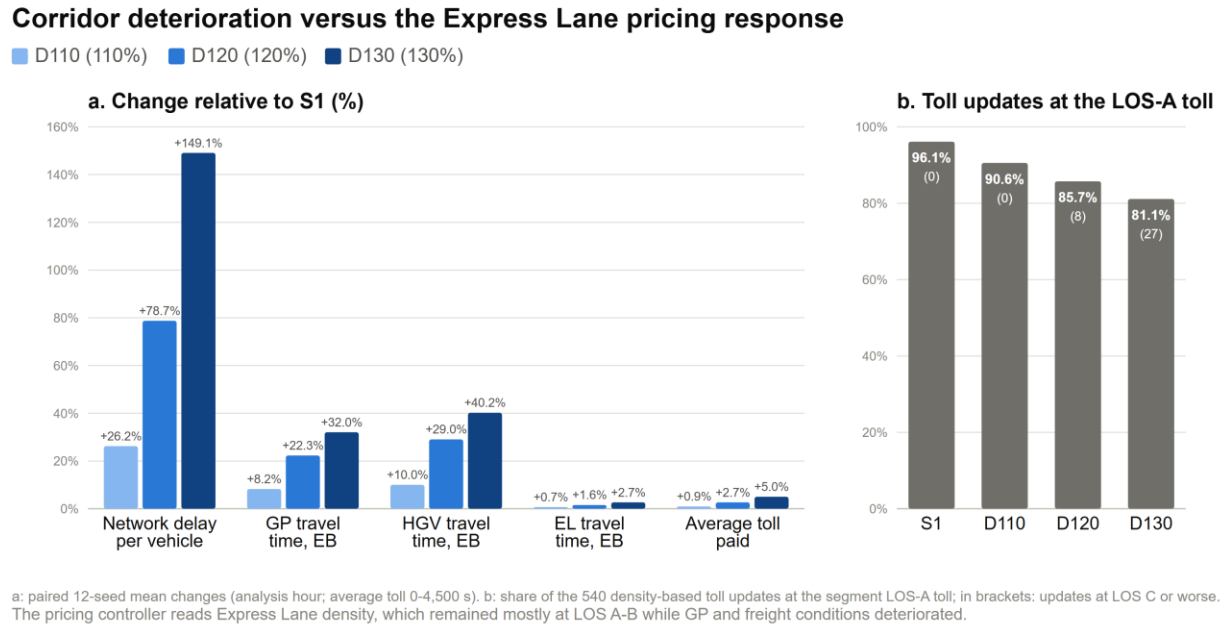


Figure 107. Corridor Deterioration versus the Pricing Response

Source: Subtask 4.3 paired 12-seed analysis (Appendix T, Sections T.4 and T.9). At D130 network delay per vehicle rises 149.1% while the average toll paid rises 5.0%; 81.1% of toll updates are still at the segment LOS-A toll.

The pricing controller responds to Express Lane density, which stays comparatively low (Table 66 and Figure 107).

Express Lane density rose with demand: the highest 15-minute density grew from 14.8 veh/mi/lane in S1 to 29.8 at D130, against an LOS C threshold of 18. Two counts of LOS C or worse must be kept apart:

- **In any 15-minute interval**, LOS C or worse occurred in 1, 12 and 12 of 12 seeds at D110, D120 and D130.
- **At a toll update**, which is what the controller acts on, it occurred in 0, 8 and 12 of 12 seeds, and in 0, 8 and 27 of the 540 density-based toll updates.

- The difference arises because the densest conditions occur after the last toll update at 4,500 s (Section 2.7).

The toll response was correspondingly modest:

- The share of toll updates at the segment's LOS-A toll fell from 96.1% in S1 to 90.6%, 85.7% and 81.1%.
- Tolls moved between LOS-bound values. Changes larger than $0.05 between successive updates occurred only at D130 (9 of 540).
- The average toll paid rose by 0.9%, 2.7% and 5.0%.
- Toll transactions rose 11.3%, 22.9% and 37.7%, and the EL share rose 2.2%, 5.7% and 11.1%: as the GP lanes congested, more price-responsive drivers chose the Express Lanes.
- Revenue rose 12.4%, 26.2% and 44.6%, but only 4.1%, 3.9% and 5.2% of each revenue change came from higher tolls. The rest came from more transactions.

Pooled over 12 seeds, the controller is effectively fixed in S1 and weakly dynamic at every increased-demand level. The controller responds as designed to Express Lane density, but EL density remains comparatively low and therefore does not reflect the magnitude of congestion developing in the GP lanes. The controller is not failing: it keeps the Express Lanes near free flow, which is its design objective. Pricing strategies themselves are evaluated in Subtask 4.2 (Chapter 1).

2.7 Discussion and Limitations

Discussion.

- As requested demand rose by 10%, 20% and 30%, the corridor moved from moderate stress (D110) to operation at or near capacity (D120 and D130).
- GP, network and freight measures deteriorated much faster than realized demand, while the Express Lanes absorbed more traffic at nearly unchanged speed.
- The density the pricing controller reads changed comparatively little, so the toll did not track the GP and freight deterioration.

Limitations.

- **Scope of the scenarios.** The scenarios are controlled sensitivity tests: demand is scaled uniformly, with the same trip pattern, vehicle mix and network. They are not forecasts.
- **Realized demand.** Realized demand grows less than requested demand, and unserved demand spreads to new entry points, reaching the I-4 mainline entries at D130. The results therefore describe the demand that could enter the network.
- **Analysis hour.** The 3,600-s analysis hour is fully simulated and paired in every scenario. At D120 and D130, however, congestion was still growing at the end of the simulation: in the final 15 minutes, eastbound GP travel time was 52.2% and 66.3% above S1. Hourly averages therefore describe the peak hour, not the full duration of the congestion episode.

- **Pricing horizon.**
    - The densest Express Lane conditions mostly occurred after the last toll update at 4,500 s: in 61%, 75% and 77% of segment-seeds at D110, D120 and D130 (S1: 31%).
    - An offline update at 5,400 s, applying the unchanged controller to the final-interval densities, would change 16, 19 and 40 of the 108 segment tolls. The largest increase would be $1.35 at D130.
    - The 5,400-s horizon is therefore sufficient for D110, partially sufficient for D120 and limiting for D130 when interpreting the late pricing response.
    - This limitation affects interpretation of the late pricing response but does not invalidate the observed demand-loading, GP operational or freight findings.
- **Controller reused unchanged.** The existing controller was reused without modification and was not re-optimized for higher demand.

Future work: dynamic versus fixed time-of-day pricing. The tested demand scenarios did not produce a sufficiently rich and consistently dynamic toll trajectory for a strong dynamic-versus-fixed time-of-day (TOD) comparison. At every level, most tolls remained at level-of-service bound values that a fixed schedule would reproduce. A future study could construct representative fixed TOD schedules from a longer simulation horizon or from empirical dynamic toll observations.

2.8 Conclusions and Implications

The future-demand sensitivity analysis shows that moderate increases in realized demand (9.6%, 18.8% and 26.9%) produced disproportionately large increases in GP travel time, network delay and freight travel time as the modeled corridor approached capacity. At D130, network delay per vehicle rose 149.1%, eastbound GP travel time 32.0% and eastbound HGV travel time 40.2%. Express Lane performance remained comparatively stable (speed change at most 3.5%). The existing EL-density-responsive tolling system showed only modest pricing changes (average toll +5.0% at D130), because Express Lane density remained much lower than the congestion developing in the GP lanes. Demand growth is the primary driver of the operational and freight deterioration observed in the modeled corridor.

Implications:

- **The existing controller protects the Express Lanes but does not respond to GP congestion.** That is consistent with its design. The GP-density-responsive alternative is assessed in Section 1.4 and Section 3.3.
- **Freight is exposed to passenger demand growth.** HGVs are confined to the GP lanes, so freight travel time and reliability follow GP congestion closely.
- **Range of results.** D110 and D120 are well-loaded stress levels; D130 is a valid upper-bound stress scenario whose results should be read together with its unserved demand.

Chapter 3 compares these demand effects with the pricing effects of Subtask 4.2 and states the integrated Task 4 conclusions.

The complete technical results, including confidence intervals, seed-level values, section-level freight results, unserved demand by entry point, controller detail and the horizon analysis, are in Appendix T.

3 Integrated Findings and Conclusions

Task 4 evaluated operational strategies for the Express Lanes and GP lanes of the modeled I-4 corridor, including their effect on freight, measured by HGV travel time. It did so through two complementary experiments:

- Held demand at the 2040 PM-peak baseline and changed the pricing strategy. It varied the toll bounds (S2_LOW, S2_HIGH) and the congestion signal the controller reads (GP-density-responsive pricing, GP_RESP, with robustness tests).
- Kept the existing pricing strategy and increased demand (D110, D120 and D130, with requested demand 10%, 20% and 30% above the baseline).

Both subtasks use the same reference runs (S1), the same 12 paired random seeds and the same performance definitions, so their results can be read side by side. Together they separate **pricing-driven effects** from **demand-driven effects**. This synthesis answers one question:

> *What do the pricing-strategy and future-demand analyses collectively show about the ability of Express Lane pricing to influence corridor operations, freight performance, lane choice and revenue under present and higher-demand conditions?*

Detailed results, statistics and classifications remain in Chapters 1 and 2 and in Appendices R, S and T.

3.1 Integrated Interpretation of Pricing and Demand Effects

Table 67. Summary of Task 4 Operational-Strategy and Future-Demand Findings (12 Paired Seeds; All Changes Relative to S1)

Scenario / strategy	Primary experimental change	Lane-choice / revenue response	GP / network response	Freight response	Main interpretation
Reduced Toll-Bound Scenario (S2_LOW)	Toll bounds x0.70; baseline demand	Average toll -23.5%; transactions +8.9%; revenue -16.6%	GP travel time within 0.2%; network delay per vehicle -0.1% (n.s.)	HGV travel time within 0.5% on every section	More Express Lane use and less revenue; no operational change
Increased Toll-Bound Scenario (S2_HIGH)	Toll bounds x1.50; baseline demand	Average toll +39.7%; transactions -14.9%; revenue +18.9%	GP travel time within 0.3%; network delay per vehicle +0.5% (n.s.)	HGV travel time within 0.8% on every section	Less Express Lane use and more revenue; no operational change
GP-Responsive Pricing Scenario (GP_RESP)	Controller reads GP density instead of EL density; baseline demand	Average toll +22.9%; transactions -11.2%; revenue +9.1%	GP travel time EB +0.8%; network delay per vehicle +1.0%	Localized deterioration on one EB section; direction totals below 2%	Stronger toll response without operational benefit; no demonstrated operational advantage

Table 67. Summary of Task 4 Operational-Strategy and Future-Demand Findings (12 Paired Seeds; All Changes Relative to S1) (continued)

Scenario / strategy	Primary experimental change	Lane-choice / revenue response	GP / network response	Freight response	Main interpretation
110% Demand Scenario (D110)	Requested demand +10% (realized +9.57%); pricing unchanged	Transactions +11.3%; average toll +0.9%	Network delay per vehicle +26.2%; GP travel time EB +8.2%	HGV travel time EB +10.0%, WB +3.0%	Moderate stress; delay grows faster than demand
120% Demand Scenario (D120)	Requested demand +20% (realized +18.77%); pricing unchanged	Transactions +22.9%; average toll +2.7%	Network delay per vehicle +78.7%; GP travel time EB +22.3%	HGV travel time EB +29.0%, WB +13.2%	Corridor at or near capacity; toll response modest
130% Demand Scenario (D130)	Requested demand +30% (realized +26.87%; unserved 3.25%); pricing unchanged	Transactions +37.7%; average toll +5.0%	Network delay per vehicle +149.1%; GP travel time EB +32.0%	HGV travel time EB +40.2%, WB +23.4%	Valid capacity-constrained stress scenario; Express Lane speed change at most 3.5%

Source: Tables 61 and 63-66 (Subtask 4.2 and 4.3 paired 12-seed analyses). All six scenarios are paired with the same S1 runs (Reference Pricing Strategy at baseline demand) over the same 12 seeds; (n.s.) = not statistically detectable. Pricing-related values cover 0-4,500 s; travel times and delay cover the 1,800-5,400-s analysis hour. GP travel time is the sum of the GP section mean travel times per direction; HGV values are directional sums of the section mean HGV travel times. GP-responsive robustness tests (reduced bounds, 80% and 120% demand) are compared with their own matched comparators and are summarized in Section 1.4 and Table 62, not here.

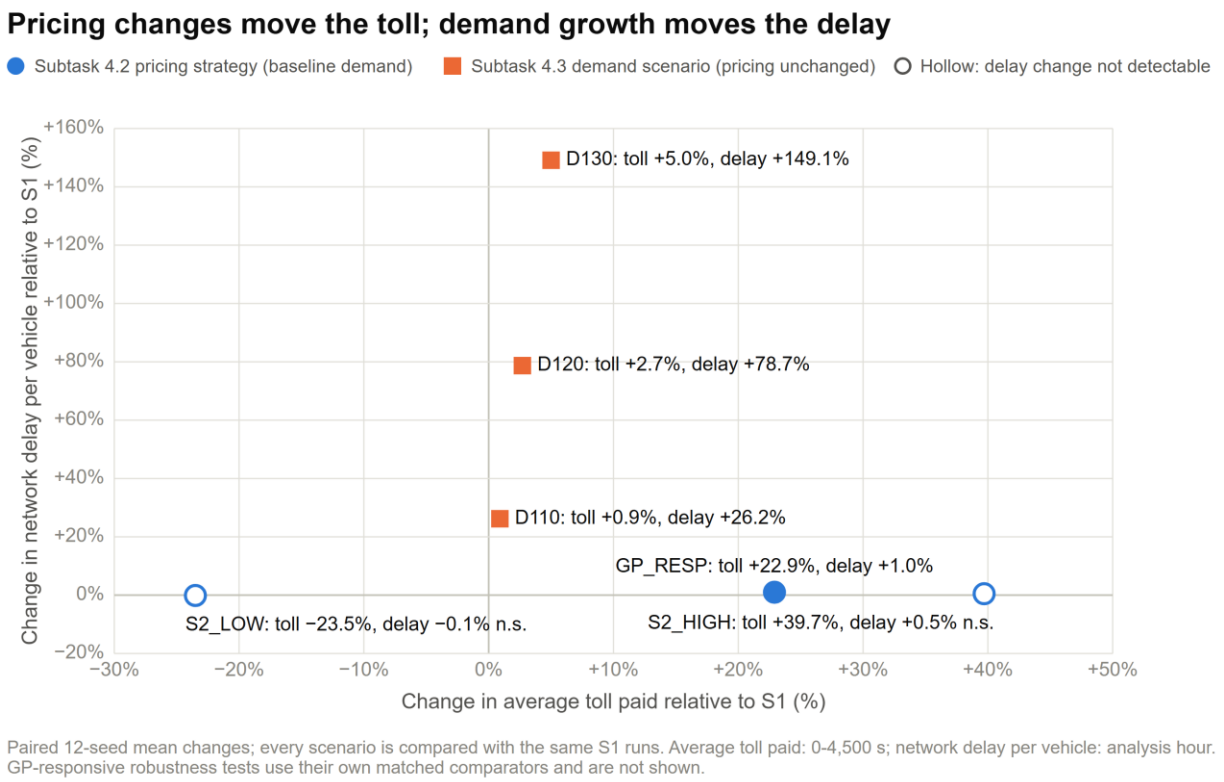


Figure 108. Toll Response versus Delay Response for the Task 4 Scenarios

Source: Tables 61, 64 and 66. The pricing strategies change the average toll paid by -23.5% to +39.7% while network delay per vehicle changes by at most 1.0%. The demand scenarios raise network delay per vehicle by 26.2% to 149.1% while the average toll changes by at most 5.0%. All six scenarios are compared with the same S1 runs.

Pricing variation changes who uses the Express Lanes and what they pay. At baseline demand (Table 67):

- lower toll bounds (S2_LOW) changed the average toll paid by -23.5%, toll transactions by +8.9% and revenue by -16.6%;
- higher toll bounds (S2_HIGH) changed them by +39.7%, -14.9% and +18.9%;
- GP-density-responsive pricing (GP_RESP) raised the average toll by 22.9% and revenue by 9.1%, while transactions fell by 11.2%.

Across all of these alternatives, GP travel time changed by at most 0.8% and network delay per vehicle by at most 1.0%.

Demand growth changes how the corridor operates. With the pricing strategy unchanged:

- realized demand rose by 9.57%, 18.77% and 26.87%;
- network delay per vehicle rose by 26.2%, 78.7% and 149.1%;
- eastbound GP travel time rose by 8.2%, 22.3% and 32.0%.

Delay grew 2.7, 4.2 and 5.5 times as fast as realized demand. Meanwhile Express Lane speed changed by at most 3.5%, and the average toll paid by at most 5.0%.

The contrast is the central Task 4 result. Pricing variation produced large behavioral and revenue effects but comparatively small operational effects at baseline demand. Demand growth produced comparatively modest changes in entered demand but disproportionately large GP, network and freight deterioration. The smallest demand step (D110) changed network delay per vehicle about 26 times as much as the strongest pricing alternative at baseline demand.

Figure 108 shows the contrast: the pricing strategies lie along the toll axis, the demand scenarios along the delay axis.

Demand growth also raised Express Lane use and revenue (transactions +37.7%, revenue +44.6% at D130), but mostly because more vehicles used the Express Lanes: only 5.2% of that revenue change came from higher tolls. Revenue therefore responds to both mechanisms, but only demand growth materially changed corridor operations. Within the modeled conditions, demand growth is the dominant driver of GP, network and freight deterioration, while the tested pricing changes predominantly affect lane choice and revenue.

3.2 Operational and Freight Implications

Operations. The Express Lanes stayed near free flow in every scenario, and congestion developed in the GP lanes:

- At baseline demand, toll changes shifted too few vehicles between the Express Lanes and the GP lanes to matter for GP travel time: GP single-occupant-vehicle volume per count station changed by at most 2.1%.
- As demand grew, the GP sections approached capacity. Eastbound GP throughput at D130 fell below S1 (-2.4%).
- The simulations show that toll policy can materially influence Express Lane demand and revenue without producing comparably large changes in corridor-wide travel time or delay.
- Conversely, relatively modest increases in realized corridor demand generated disproportionately large changes in GP and freight performance.

Freight. HGVs do not use the Express Lanes, so freight performance follows conditions in the GP lanes:

- **Toll bounds:** HGV travel time changed by at most 0.5% (S2_LOW) and 0.8% (S2_HIGH) on any section, so the changes had little freight effect.
- **GP-responsive pricing:** it did not provide a consistent freight advantage. At baseline demand its effect was localized to one eastbound section, with both direction totals below 2% (+0.8% eastbound, +0.4% westbound). At 120% demand the section-level results differed in sign, and the supplementary corridor evidence showed westbound HGV travel time +3.6%.
- **Demand growth:** with pricing unchanged, mean HGV travel time rose by up to 40.2% eastbound and 23.4% westbound at D130. The 95th-percentile truck travel time increased

on every section at every demand level, and network delay per HGV (+171.2% at D130) grew faster than network delay per vehicle overall.

Freight degradation is therefore primarily associated with growing GP congestion rather than with direct HGV participation in the pricing system, and none of the tested pricing changes offset it.

3.3 Pricing-System Implications

What pricing does well. Toll level reliably controls lane choice and revenue. Price-responsive demand was inelastic (approximate elasticities -0.32 and -0.48), so revenue moved with the toll: lower bounds drew more drivers into the Express Lanes and lost revenue, higher bounds did the reverse. These are legitimate functions of Express Lane pricing.

The existing controller. The existing controller responds to Express Lane density as designed. Because Express Lane density remains comparatively low even as GP congestion increases, the pricing signal does not fully reflect the deterioration occurring in the GP lanes. At D130, 81.1% of toll updates were still at the lowest (LOS-A) segment toll, and the average toll paid rose 5.0% while network delay per vehicle rose 149.1%.

A GP-based signal. Replacing the EL-density input with GP density increased controller activity substantially: tolls were higher than in S1 in 400 of 540 (74%) segment updates at baseline demand. The stronger response did not produce an operational advantage. Under elevated demand it was associated with adverse GP effects: relative to D120, westbound GP travel time +3.8% and network delay per vehicle +6.8%. The mechanism is that higher GP-triggered tolls moved vehicles out of the Express Lanes and into the congested GP lanes. Subtask 4.2 classifies the 120% comparison as mixed-tradeoff (Section 1.4), and states its overall GP-responsive finding as: no demonstrated operational advantage; no further testing of the current GP-responsive formulation is recommended.

Implication. Within the modeled conditions, neither the tested toll levels nor the GP-based signal offset the deterioration caused by demand growth. This does not mean that Express Lane pricing is ineffective. It performs its lane-choice and revenue functions and protects Express Lane performance, but those functions are distinct from relieving GP and freight congestion.

3.4 Study Limitations and Future Research

Limitations.

- The results are simulation-based sensitivity tests for one modeled corridor under 2040 PM-peak conditions and should not be generalized to all Express Lane facilities.
- The pricing strategies reuse the existing controller framework without re-optimization. The GP-responsive formulation is one of many possible designs.
- The demand scenarios scale every input uniformly and are not forecasts. Realized demand grows less than requested demand. D130, with 3.25% of requested demand unserved, is a valid high-demand stress scenario within the study's loading criteria.

- The 5,400-s simulation horizon limits observation of the late-period pricing response, but not the loading, operational or freight findings.

Time-of-day pricing. A future comparison of dynamic and fixed TOD pricing would require either a longer simulation window or empirical dynamic toll observations sufficient to establish representative TOD schedules.

Future research directions. These are directions for future study, not recommendations for implementation; no additional simulation is recommended for the present project:

- alternative operational controls;
- access and egress management;
- demand management;
- pricing formulations with broader system objectives;
- longer-horizon TOD development.

3.5 Task 4 Conclusions

1. What primarily changes when toll levels change? Lane choice, Express Lane use, toll transactions, the average toll and revenue. Corridor operations change little at baseline demand: at most 0.8% in GP travel time and 1.0% in network delay per vehicle.

2. What primarily changes when demand increases? GP travel time, network delay and freight travel time and reliability. They deteriorate disproportionately as the corridor approaches capacity, while Express Lane performance and the average toll change comparatively little.

3. Did stronger pricing responsiveness materially improve corridor operations? No. GP-density-responsive pricing made the toll far more active but showed no demonstrated operational advantage, and under elevated demand it was associated with adverse GP effects.

4. What happens to freight as corridor demand increases? Freight travel time and reliability worsen in both directions, because HGVs remain in the increasingly congested GP lanes. None of the tested pricing changes provided a consistent freight benefit.

5. Does the existing EL-density controller react to worsening GP congestion? Only indirectly and modestly. As the GP lanes congest, more drivers choose the Express Lanes, which raises Express Lane density and moves some tolls up one level-of-service step. The controller responds to that density as designed, but Express Lane density stays comparatively low, so its toll signal does not reflect the magnitude of GP congestion.

6. What does the combined evidence imply for future strategy development? The combined analyses indicate that further operational-strategy development should focus not only on toll magnitude or alternative congestion signals, but also on strategies capable of addressing the underlying growth in corridor demand and GP congestion.

Conclusion.

- The Task 4 analyses distinguish the effects of pricing strategy from the effects of demand growth. Changes in toll magnitude substantially affected Express Lane utilization and revenue but produced comparatively small corridor-wide operational changes under baseline demand.
- Increasing demand, by contrast, produced disproportionately large increases in GP travel time, network delay and freight travel time, while Express Lane performance remained comparatively stable.
- The existing EL-density-responsive controller responded only modestly, because Express Lane density remained lower than the congestion developing in the GP lanes. A GP-density-responsive sensitivity produced a stronger pricing response but did not demonstrate an operational advantage.
- Collectively, these findings indicate that demand growth is the dominant driver of operational and freight deterioration within the modeled conditions. The tested pricing strategies primarily influence lane choice and revenue rather than offsetting that deterioration.

3.6 Future Research on Express Lane Operations and Freight Mobility

Taken together, the findings of this report also point to a direction for future research on the relationship between Express Lane operations and freight mobility. The report provides scenario-based evidence, in Parts III to V, on how incidents, congestion, pricing strategies and future demand affect heavy goods vehicles (HGVs). Much of this evidence is modeled: freight effects were measured through HGV-specific simulation outputs, such as HGV delay and travel time, and through operating conditions in the general-purpose (GP) lanes, where HGVs remain in the Part III and Part V models. The observed freight data available to the study were fragmented: direct access to the MCSAW/FOX weigh-in-motion (WIM) platform was not available to the research team, WIM coverage varies by corridor (Part I), and facility-specific trajectory data were not available for all study corridors (Part II). The findings therefore support useful scenario-level conclusions while also identifying an opportunity for more direct, freight-specific empirical evaluation.

Two results illustrate this opportunity. In the incident analysis (Part III), much of the difference between HGV and passenger-vehicle impacts reflected the greater exposure of HGVs, which remain in the GP lanes where the incidents occurred. In Task 4, HGV travel time and reliability deteriorated as GP congestion grew with demand, while Express Lane operations remained comparatively stable, and none of the tested pricing changes provided a consistent freight benefit. In both cases, the freight effects are modeled HGV responses to conditions in the GP lanes rather than direct observations of freight movement.

Future research should therefore consider more comprehensive, continuous and vehicle-class-specific observed data where available, such as freight probe-vehicle trajectories, truck GPS or telematics data, classified traffic counts, WIM observations and other vehicle-class-specific

trajectory or reliability data. Such data would allow HGV travel time, travel-time reliability, congestion exposure and the interaction between GP-lane and managed-lane operations to be evaluated more directly, and could support future evaluation of freight route choice and corridor-level responses, which were outside the scope of the present simulations. Combined with microsimulation and managed-lane operational data, these observations could provide a stronger empirical basis for understanding how Express Lane strategies affect freight mobility and for identifying whether operational or pricing strategies can improve overall corridor performance without adverse effects on freight movement.

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Appendix A. Detailed Scenario Matrix

The complete scenario matrix (46 scenarios across 5 corridors) is provided in the companion file: FDOT_Master_Scenario_Matrix.csv. Key attributes per scenario include VISSIM version, simulation period, warm-up period, stochastic run count, random seed, link count, result format, and result accessibility status.

Appendix B. Corridor Characteristics

Detailed corridor characteristics for all five corridors are provided in the companion file: FDOT_Master_Corridor_Characteristics.csv. Attributes include: FPID, FDOT district, county, from and to termini, approximate length, facility type, speed limit, base-year AADT, express-lane configuration, analysis years, SIS designation, and study type.

Appendix C. Model Configuration

Per-INPX model configuration details for all 35 INPX files are provided in: FDOT_Master_Model_Configuration.csv. Attributes include VISSIM version, simulation period, warm-up, run count, random seed, link count, signal controller count, HGV type and class, HGV composition, managed-lane facility count, and allVehTypes setting.

Appendix D. Managed-Lane and Tolling Features

Managed-lane facility details for all five corridors are provided in: FDOT_Master_Managed_Lane_Features.csv. Attributes include toll type, toll range, update interval, diversion model parameters, allVehTypes setting, HGV eligibility status, HOV provisions, and VBScript architecture summary.

Appendix E. Freight-Relevance Assessment

Per-corridor freight-relevance assessments are provided in: FDOT_Master_Freight_Relevance.csv. Includes HGV type, composition, ML eligibility, result accessibility, SIS designation, and overall relevance rating per scenario.

Appendix F. Verified Numerical Findings

All 38 verified numerical values are documented in: FDOT_Master_Verified_Numerical_Findings.csv. Each entry includes finding ID, source package, corridor, scenario, analysis year, period, vehicle class, measure, value, units, source file, source table or location, verification status, and interpretation caveats.

Appendix G. Numerical Audit

The complete numerical audit trail — including original reported values, corrected values where applicable, verification method, and QC status — is provided in: FDOT_Master_Numerical_Findings_Audit.csv. All QC corrections identified in this review are documented with before and after values and evidence citations.

Appendix H. Technical Risks

The technical risk register (17 risks across five corridors, classified as Critical, High, Medium, or Low) is provided in: FDOT_Master_Technical_Risk_Register.csv. Each risk entry includes corridor, category, severity, issue description, evidence, impact, recommended mitigation, responsible party, and priority.

Appendix I. Recommended Data Requests and Reruns

The complete list of 18 data requests and 7 rerun specifications is provided in: FDOT_Recommended_Data_Requests.csv and FDOT_Recommended_Model_Reruns.csv. Each entry includes corridor, item, responsible party, priority level, and justification.

Appendix J. Source-Reference Index

All source references used in this report are indexed in: FDOT_Master_Source_Reference_Index.csv. Each entry includes a source identifier (prefix I4-SRC, I295-SRC, or COMB-SRC), corridor, file name, file type, applicable report sections, key evidence, and verification method.

Appendix K. File and Archive Review Summary

The complete file inventory (44 entries across both archives) is provided in: FDOT_Master_File_Inventory.csv. The folder tree summary for both source archives is provided in: FDOT_Combined_Folder_Tree.txt. Items requiring manual review or specialized software are documented in: FDOT_Combined_Manual_Review.txt.

Appendix L. Acronyms and Definitions

See the Acronyms and Abbreviations section in the Front Matter of this report for a complete list of abbreviations and their definitions.

CONSOLIDATED APPENDICES

Appendix A. Project Scope and Contract Information

Project scope, contract number, FDOT project number, and contract deliverable schedule. To be completed by the research team and FDOT project manager.

Appendix B. Deliverable 1 — References and Bibliography

Full bibliography and reference list for the literature review conducted under Deliverable 1 (Part I of this report). Source references cited in Chapters 1 through 4 are listed in the Deliverable 1 source document.

Appendix C. Deliverable 2 — References and Supporting Data

Reference list and supplementary data tables for the empirical analysis conducted under Deliverable 2 (Part II). Includes complete NPMRDS and FDOT Traffic Online data queries, facility summary statistics, and additional before-and-after comparison tables not included in the main body.

Appendix D. Deliverable 3 — References

Reference list for the VISSIM model development and incident analysis conducted under Deliverable 3 (Part III).

Appendix E. Deliverable 3 — Model Development and Calibration Details

Complete VISSIM model object inventory, calibration parameter tables, volume and speed calibration results by link, number-of-runs analysis, and per-link comparison tables for the I-95 Express VISSIM model.

Appendix F. Deliverable 3 — Incident Scenario Summary Statistics

Network-wide incident results for the nine incident scenarios (SC-01 to SC-08, including SC-02B) in the I-95 Express VISSIM model are presented in Part III (Table 46 and Table 47); per-interval delay changes are shown in **Figure 93** and **Figure 94**. Scenario configuration, seed-level paired results, latent delay, the comparison with previously reported values and comparable-section travel times are given in Appendix U.

Appendix G. Corridor Characteristics — Express-Lane Model Review

Detailed corridor characteristics for the five reviewed FDOT express-lane corridors (SR 414, I-4 Ultimate, I-4 South, I-295 East, I-295 West). Companion file: FDOT_Master_Corridor_Characteristics.csv

Appendix H. Express-Lane Model Inventory

Complete scenario matrix (46 scenarios across 5 corridors) with VISSIM version, simulation period, warm-up period, stochastic run count, random seed, link count, result format, and accessibility status. Companion file: FDOT_Master_Scenario_Matrix.csv

Appendix I. Managed-Lane and Tolling Features

Managed-lane facility details for all five reviewed corridors: toll type, toll range, update interval, diversion model parameters, allVehTypes setting, HGV eligibility, HOV provisions, and VBScript architecture. Companion file: FDOT_Master_Managed_Lane_Features.csv

Appendix J. Freight and HGV Representation

Per-corridor freight-relevance assessments: HGV type, composition, ML eligibility, result accessibility, SIS designation, and relevance rating per scenario. Companion file: FDOT_Master_Freight_Relevance.csv

Appendix K. Verified Numerical Findings

All 38 verified numerical values from the express-lane model review with traceability to source file, scenario, analysis year, period, vehicle class, measure, value, units, and verification method. Companion file: FDOT_Master_Verified_Numerical_Findings.csv

Appendix L. Numerical Findings Audit

Complete audit trail including original reported values, corrected values, verification method, and QC status for all reviewed numerical findings. QC corrections: I-4 South No-Build link count revised from 1,241 to 1,090; total stochastic runs revised from 120 to 100. Companion file: FDOT_Master_Numerical_Findings_Audit.csv

Appendix M. Model Configuration and Object Summary

Per-INPX model configuration details for all 35 reviewed INPX files: VISSIM version, simulation period, warm-up, run count, random seed, link count, signal controller count, HGV type and class, HGV composition, ML facility count, and allVehTypes setting. Companion file: FDOT_Master_Model_Configuration.csv

Appendix N. Technical Risk Register

17 technical risks across five corridors, classified as Critical, High, Medium, or Low. Each entry includes corridor, category, severity, issue description, evidence, impact, recommended mitigation, responsible party, and priority. Companion file: FDOT_Master_Technical_Risk_Register.csv

Appendix O. Recommended Data Requests and Model Reruns

18 data requests and 7 rerun specifications (the 13 highest-priority items are listed in Table 59) for the reviewed FDOT model packages. Companion files: FDOT_Recommended_Data_Requests.csv; FDOT_Recommended_Model_Reruns.csv

Appendix P. Source Reference Index

Complete source-reference index for the express-lane model review. Source prefixes: I4-SRC (I-4 package sources), I295-SRC (I-295 package sources) and COMB-SRC (combined-review sources). Companion file: FDOT_Master_Source_Reference_Index.csv

Appendix Q. File and Archive Review Summary

Complete file inventory (44 entries) for both source archives reviewed in Part IV, including the folder tree structure and a list of files requiring manual review or specialized software. Companion files: FDOT_Master_File_Inventory.csv; FDOT_Combined_Folder_Tree.txt

Appendix R. Task 4 — S1/S2 Pricing Technical Analysis (Toll-Bound Sensitivities)

About this appendix. This appendix reproduces, as a dated record, the toll-bound technical report "Express Lane Pricing Scenarios: Technical Report", which supports Part V, Chapter 1. Its text and values are unchanged. For this report its sections are numbered R.1-R.19 and R.A-R.G (numbered 1-19 and A-G in the source report), its tables are numbered and captioned, and its internal cross-references are renumbered accordingly. Its Section R.18 and the last bullet of its executive summary predate subtask and are superseded by Part V, Chapters 2 and 3. Terminology differs from Part V in places: "managed-lane decision" = toll decision point; "General-Purpose" = general-purpose (GP); "statistically significant" = paired t-test $p < 0.05$, which coincides with "statistically detectable" for every value cited in Part V. Percentages are reported here to two decimals; Part V rounds once from full precision to one decimal (for example, S2_LOW revenue -16.6467% is -16.65% here and -16.6% in Table 61).

Project: FDOT Managed Lanes – I-4 Express Lanes, 2040 North Modified Build, PM peak (PTV Vissim 2020 SP14, Python 3.7 toll controller)

Task: 4.2 – Sensitivity of Express Lane operations, General-Purpose Lane operations and freight mobility to Express Lane toll levels

Scenarios: S2_LOW (0.70× LOS toll bounds), S1 (1.00×, existing control), S2_HIGH (1.50×)

Basis: validated 12-seed paired simulation batches; all values are taken from the approved Task 4.2 validation files listed in Section R.G

Executive Summary of the Toll-Bound Technical Report

Three Express Lane (EL) pricing scenarios were simulated with 12 identical random seeds and compared seed by seed. Only the level-of-service (LOS) based toll bounds differed between scenarios; network, demand, routing, signal, vehicle, freight and evaluation settings were identical.

- **Lane choice responded strongly and consistently.** Relative to S1, toll transactions changed by +8.90% under S2_LOW and -14.85% under S2_HIGH, and the EL share at the managed-lane decisions changed by +11.25% and -18.28% (relative). These changes were statistically significant and occurred in the same direction in all 12 seeds.
- **Revenue followed the price.** The average toll paid changed by -23.45% (S2_LOW) and +39.68% (S2_HIGH); because price-responsive demand was inelastic (approximate arc elasticity -0.32 and -0.48), toll revenue changed by -16.65% and +18.94%.
- **EL operating conditions remained uncongested in every scenario.** No toll update reached LOS C or worse; analysis-hour directional EL speeds stayed between 67.00 and 70.85 mph, and no EL section speed changed by more than 0.38%.
- **General-Purpose (GP) and freight effects were small.** The largest change in GP section travel time was 0.42% (S2_LOW) and 0.64% (S2_HIGH); the largest change in mean

heavy-goods-vehicle (HGV) travel time was 0.48% and 0.84%. Several of these changes were statistically detectable, but none reached the project's 2% practical-significance threshold, and pooled hourly HGV 95th-percentile travel time and buffer index did not change significantly on any section.

- **Conclusion.** Under baseline demand the primary effects of the toll level are on lane choice, toll transactions and revenue. Lower tolls did not produce a measurable indirect freight benefit and higher tolls did not produce a measurable freight penalty. Increased-demand testing (Task 4.3) is required to determine whether pricing becomes operationally important when the Express Lanes approach congested conditions.

R.1 Purpose

The purpose of Task 4.2 is to evaluate how systematic changes in Express Lane toll levels affect lane choice, toll revenue, Express Lane operations, General-Purpose Lane operations and freight mobility on the I-4 corridor.

- **S1** is the validated existing-pricing control (S1_EXISTING_ANALYSIS).
- **S2_LOW** reduces the LOS-based toll bounds (minimum and maximum toll per mile for each LOS band) by 30% (0.70×).
- **S2_HIGH** increases the LOS-based toll bounds by 50% (1.50×).
- All other network, demand, routing, signal, vehicle, freight and evaluation settings are unchanged between the three scenarios (Section R.4).
- The same 12 random seeds are used in every scenario so that each pricing scenario is compared with S1 seed by seed (paired comparison).

R.2 Scenario Definitions

Table 68. Toll-Bound Pricing: Scenarios and LOS Toll Multipliers

Scenario	LOS toll multiplier	Purpose
S2_LOW	0.70×	Reduced-toll sensitivity
S1	1.00×	Existing pricing control
S2_HIGH	1.50×	Increased-toll sensitivity

LOS-based toll bounds in `tolling_python37_compat\mlf_config.ini` (dollars per mile, LOS A, B, C, D, E, F):

Table 69. Toll-Bound Pricing: LOS-Based Toll Bounds by Scenario

Scenario	mintoll_los ($/mi)	maxtoll_los ($/mi)
S2_LOW	0.105, 0.105, 0.119, 0.196, 0.462, 1.001	0.105, 0.112, 0.161, 0.392, 0.966, 1.400
S1	0.15, 0.15, 0.17, 0.28, 0.66, 1.43	0.15, 0.16, 0.23, 0.56, 1.38, 2.00
S2_HIGH	0.225, 0.225, 0.255, 0.420, 0.990, 2.145	0.225, 0.240, 0.345, 0.840, 2.070, 3.000

Parameters held constant in all three scenarios: minimum segment toll (`min_seg_toll`) = $0.25; toll rounding (`toll_round`) = $0.05, rounded up; toll-update interval = 900 s; LOS density thresholds = 11 / 18 / 26 / 35 / 45

veh/mi/ln (LOS A–F); `TollCalc_v7.py`, `funcs_v7.py` and `delta.csv` byte-identical to S1; combination (multi-segment) facility toll = sum of the constituent segment tolls.

Source: `S2_LOW_12RUN_FINAL_VALIDATION.txt`; `S2_HIGH_12RUN_FINAL_VALIDATION.txt`.

Representative LOS-A segment tolls. At LOS A the minimum and maximum bounds are equal, so a segment at LOS A is priced at a single value. The resulting segment tolls (after the $0.05 round-up and the $0.25 minimum) are:

Table 70. Toll-Bound Pricing: Representative LOS-A Segment Tolls by Scenario

Segment	Direction	Location	Length (mi)	S2_LOW ($)	S1 ($)	S2_HIGH ($)
1	EB	EB Lake Mary - 417 Eg	0.88	0.25	0.25	0.25
2	EB	EB 417 Eg - 417 In	1.58	0.25	0.25	0.40
3	EB	EB 417 In - Dirksen	4.09	0.45	0.65	0.95
4	EB	EB Dirksen - OCR	7.61	0.80	1.15	1.75
5	WB	WB OCR - Dirksen	7.24	0.80	1.10	1.65
6	WB	WB Dirksen - 417	4.90	0.55	0.75	1.15
7	WB	WB 417 - 46A	2.00	0.25	0.30	0.45
8	WB	WB 46A - Lake Mary	2.60	0.30	0.40	0.60
9	WB	WB Lake Mary - I-4	4.27	0.45	0.65	1.00

Source: `S2_LOW_S1_S2_HIGH_TOLL_BEHAVIOUR_BY_SEGMENT.csv`; `S1_LOS_BOUND_ACTIVITY.csv`.

Examples of combination-facility tolls at LOS A (sum of segment tolls; verified against the first toll update of every run): Facility 78 (Segment 9) $0.45 / $0.65 / $1.00; Facility 73 (Segments 5–7) $1.60 / $2.15 / $3.25; Facility 72 (Segments 5–9) $2.35 / $3.20 / $4.85 (S2_LOW / S1 / S2_HIGH).

R.3 Experimental Design

Random seeds. Each scenario was simulated with the same 12 random seeds: 2222, 3333, 4444, 5555, 6666, 7777, 8888, 9999, 11110, 12221, 13332, 14443. The simulation period is 5,400 s (1,800 s warm-up plus a 3,600 s analysis hour) at 10 time steps per second.

Pairing. Runs were matched by the random seed stored in each run's results database, not by output run number, because run numbering differs between packages:

Table 71. Toll-Bound Pricing: Seed-to-Run Pairing for S1, S2_LOW and S2_HIGH

Seed	S1 run	S2_LOW run	S2_HIGH run
2222	_002	_001	_002

Seed	S1 run	S2_LOW run	S2_HIGH run
3333	_003	_002	_003
4444	_004	_003	_004
5555	_005	_004	_005
6666	_006	_005	_006
7777	_007	_006	_007
8888	_008	_007	_008
9999	_009	_008	_009
11110	_010	_009	_010
12221	_011	_010	_011
13332	_012	_011	_012
14443	_013	_012	_013

The S1 package contains a standalone seed-2222 check run (_001) in addition to its 12-run batch (_002–_013). The S2_HIGH package contains 13 runs: the 12-run batch (_002–_013) and an extra seed-2222 run (_001). The extra run was verified to be identical to batch run _002 (MLE output, raw travel times, warnings and all 7 results-database tables) and was **excluded from all inferential statistics**, so seed 2222 is counted once in every scenario.

Source: `S2_HIGH_12RUN_FINAL_VALIDATION.txt; S1_ANALYSIS_12RUN_FINAL_VALIDATION.txt`.

Paired comparison. For every metric and seed *i*, the paired differences S2_LOW(seed *i*) − S1(seed *i*) and S2_HIGH(seed *i*) − S1(seed *i*) were computed. Reported statistics are the scenario means, the mean paired difference, the percent change (mean difference divided by the S1 mean), the standard deviation, median, minimum and maximum of the paired differences, the 95% confidence interval of the mean difference (Student t, 11 degrees of freedom), the two-sided paired t-test, the exact two-sided Wilcoxon signed-rank test and the effect size d_z (mean difference divided by the standard deviation of the differences). Pooled HGV reliability statistics (95th-percentile travel time, buffer index, planning time index) combine the raw travel-time records of all 12 seeds; their uncertainty was estimated with a bootstrap over seed pairs (4,000 resamples), because pooled records are not independent observations.

Analysis periods. Managed-lane evaluation (MLE) quantities – toll transactions, revenue, VehML, VehGPL – cover 0–4,500 s, because the MLE output has no interval after the last toll update at 4,500 s. Travel times, link results, network performance and raw HGV travel times cover the 1,800–5,400 s analysis hour; detector-based densities are reported for the analysis hour unless stated otherwise.

Significance conventions used in this report. "Statistically significant" means paired t-test $p < 0.05$; results flagged with an asterisk (*) are significant under both the paired t-test and the exact Wilcoxon signed-rank test. "Practically meaningful" refers to the project analytical thresholds in Section R.12. Means and differences are rounded independently from unrounded values, so a displayed difference can differ in the last digit from the difference of the displayed means.

R.4 Validation and Scenario Integrity

Table 72. Toll-Bound Pricing: Validation and Scenario Integrity Checks

Check	S1	S2_LOW	S2_HIGH
12 paired runs completed (5,400 s, complete MLE and travel-time outputs)	YES	YES	YES
Errors / fatal errors / Python, COM, toll-script, database lines	0 / 0 / 0	0 / 0 / 0	0 / 0 / 0
`mlf_error.err` present	NO	NO	NO
MLE tolls reproduced from detector data (12 seeds × 25 segments/facilities × 6 updates)	1800/1800	1800/1800	1800/1800
Differs from S1 only in `mintoll_los` / `maxtoll_los` (×0.70 / ×1.50)	control	YES	YES
HGVs on Express Lanes (178 detectors, sections 501–509, EL links)	0	0	0
Freight outputs valid (raw HGV counts reconcile with VISSIM aggregates)	YES	YES	YES
Approved for Task 4.2 analysis	YES	YES	YES

Source: `S1_ANALYSIS_12RUN_FINAL_VALIDATION.txt`; `S2_LOW_12RUN_FINAL_VALIDATION.txt`; `S2_HIGH_12RUN_FINAL_VALIDATION.txt`.

Run warnings in all three batches were of the same three types – decision-73 travel-time notices, end-of-period vehicle-input backlog notices and occasional lane-change removals – with one exception: a single missed-connector notice in one S2_LOW run (one vehicle on a static route at the end of general-purpose link 291). The same notice appears in a diagnostic run shipped with the validated model (`2040_N_Modified_Build_PM_Diag08_001.err`); it is a stochastic lane-change event, not a Python, COM, toll-script, database or managed-lane failure. For both S2 scenarios, every model container other than the stored toll start values is identical to S1 – geometry, vehicle inputs, compositions, static and managed-lane routing, signals, driving behaviour, vehicle classes, travel-time sections and evaluation settings – and the 177 class-20 (HGV) lane restrictions are unchanged. Raw vehicle travel times are written to file (database output off) in all three scenarios.

The S2_LOW batch was recomputed with the final three-way analysis code and reproduced all 397 approved S2_LOW paired results (0 differences), so S2_LOW and S2_HIGH are evaluated with identical metric definitions.

R.5 Toll Behaviour

Table 73. Toll-Bound Pricing: Toll Behavior Summary by Scenario

Measure	S2_LOW	S1	S2_HIGH
Average toll paid per transaction, all decisions ($, 0–4,500 s)	0.7193	0.9397	1.3125
Toll transactions, all decisions (veh, 0–4,500 s)	3,441.6	3,160.4	2,691.1
Toll updates at LOS B (of 540 segment updates, 900–4,500 s)	86	66	41
Toll updates at LOS C or worse (of 540)	0	0	0
Toll changes between successive updates (of 540)	24	24	6
Outcomes strictly inside a LOS band, i.e. not set by a bound (%)	1.3	0.9	0.2
Maximum distinct toll values on any segment	2	2	2
Largest toll range on any segment ($)	0.05	0.05	0.05
Highest segment density at any toll update (veh/mi/ln; segment)	15.34 (Seg 1)	14.77 (Seg 1)	14.48 (Seg 1)

Source: *S2_LOW_S1_S2_HIGH_FINAL_COMPARISON.csv; S2_LOW_S1_S2_HIGH_TOLL_BEHAVIOUR_BY_SEGMENT.csv; S2_HIGH_12RUN_FINAL_VALIDATION.txt.*

Under baseline demand all three scenarios operate overwhelmingly at LOS A and B, and **no segment reaches LOS C at any toll update in any scenario or seed** (highest density 15.34 veh/mi/ln, against the LOS C threshold of 18 veh/mi/ln). In every scenario each segment toll took at most 2 distinct values – the LOS-A value and, on the few segments that reached LOS B, one $0.05 step above it. Higher tolls reduced EL density, so LOS B occurred less often (LOS B updates: 86 / 66 / 41) and the toll moved less often (24 / 24 / 6 changes; S2_LOW / S1 / S2_HIGH). S2_HIGH segment and facility tolls were higher than S1 in 1,584 of 1,800 paired comparisons and equal in 216 (all at the $0.25 minimum); S2_LOW tolls never exceeded S1 (0 cases).

The existing dynamic controller is effectively constrained by its LOS bounds under baseline demand. In the S1 control, 627 of 648 segment tolls (96.8%) equal the configured LOS-A toll; the LOS bounds determine 99.1% of controller outcomes (clipped at the LOS maximum 98.0%, at the minimum 1.1%, strictly inside a band 0.9%). Because the minimum and maximum are equal at LOS A and the LOS-B band is only $0.01 per mile wide, the toll increments in `delta.csv` are clipped: scaling every `delta.csv` step by 0.1 or by 10 changes 1 and 0 of 540 S1 toll updates, respectively. Changing the LOS bounds therefore moves the entire toll table up or down, while the

time variation of tolls remains limited to a single $0.05 step on a few segments. Express Lane speeds remain near free-flow levels (Section R.8), and the toll level changes lane choice far more than it changes operating conditions.

Source: `S1_DYNAMIC_TOLL_VARIABILITY_AUDIT.txt`; `S1_LOS_BOUND_ACTIVITY.csv`.

Segment-level toll statistics (mean, standard deviation, range, LOS occurrence, toll changes and bound status) are given in Section R.F.

R.6 Lane-Choice Results

Price-responsive versus total Express Lane traffic. Not all EL traffic meets a toll decision. *Price-responsive* traffic consists of single-occupant vehicles (SOV, vehicle class 10) that reach one of the 16 managed-lane routing decisions and choose between the managed (tolled) route and the general-purpose route; the MLE records their route completions as VehML (managed route) and VehGPL (general-purpose route), and toll transactions are computed as revenue divided by the toll in force. *Total* EL traffic additionally includes flows that use the Express Lanes without a toll decision: the EB EL boundary input (input 61, which starts on EL link 516), the WB arterial ramp to Segment 5 (links 1630 → 630), and the general-purpose routes of decisions 72 and 75, which run over Segment 9 EL links. Segment 8 lies only on the managed routes of decisions 72 and 75, which carried no managed-route demand in any seed of any scenario (Section R.E), so its price-responsive component is zero.

Source: `S1_ANALYSIS_12RUN_FINAL_VALIDATION.txt`; `S1_PRICE_RESPONSIVE_EL_SUMMARY.csv`.

Table 74. Toll-Bound Pricing: Toll Transactions and EL Share by Direction (0-4,500 s)

Measure (0–4,500 s)	Dir.	S2_LOW	S1	S2_HIGH	LOW vs S1	HIGH vs S1
Toll transactions (veh)	All	3,441.6	3,160.4	2,691.1	+8.90%*	-14.85%*
Toll transactions (veh)	EB	840.4	756.6	627.7	+11.08%*	-17.04%*
Toll transactions (veh)	WB	2,601.2	2,403.8	2,063.4	+8.21%*	-14.16%*
VehML – managed-route completions (veh)	All	2,835.2	2,559.5	2,101.8	+10.77%*	-17.88%*
VehML – managed-route completions (veh)	EB	736.6	662.9	548.5	+11.11%*	-17.26%*
VehML – managed-route completions (veh)	WB	2,098.6	1,896.6	1,553.3	+10.65%*	-18.10%*
VehGPL – GP-route completions at decisions (veh)	All	11,012.3	11,348.4	11,874.0	-2.96%*	+4.63%*
VehGPL – GP-route completions at decisions (veh)	EB	3,220.6	3,318.7	3,451.6	-2.96%*	+4.00%*
VehGPL – GP-route completions at decisions (veh)	WB	7,791.8	8,029.8	8,422.4	-2.96%*	+4.89%*
EL share at managed-lane decisions (%)	All	20.47	18.40	15.04	+11.25%*	-18.28%*
EL share at managed-lane decisions (%)	EB	18.61	16.65	13.71	+11.81%*	-17.63%*
EL share at managed-lane decisions (%)	WB	21.22	19.11	15.57	+11.05%*	-18.50%*

Percent changes are relative to S1 (for the EL share, a relative change of the share, not a percentage-point difference). = significant under both the paired t-test and the exact Wilcoxon test ($p < 0.05$).*

Source: `S2_LOW_S1_S2_HIGH_FINAL_COMPARISON.csv`; `S1_vs_S2_LOW_PAIRED_METRICS.csv`; `S1_vs_S2_HIGH_PAIRED_METRICS.csv`.

Toll transactions changed by +8.90% under S2_LOW (95% CI of the mean difference [+266.4, +295.9] veh) and by -14.85% under S2_HIGH ([-491.6, -447.1] veh). The EL share at the managed-lane decisions rose from 18.40% to 20.47% under S2_LOW (+11.25% relative) and fell to 15.04% under S2_HIGH (-18.28% relative). The direction of the share change was the same in

12 of 12 seeds under S2_LOW and 12 of 12 seeds under S2_HIGH, and at the decision level the share moved in the expected direction at every decision with an interior S1 share and a toll change (Section R.E).

Because upstream decisions alter the number of vehicles reaching downstream decisions, the EL share at each decision is the preferred decision-level indicator. For example, under S2_HIGH fewer vehicles enter the Express Lanes at the upstream WB decisions 71, 73 and 74, so more vehicles reach decision 77 in the GP lanes; its transactions increase even though its EL share decreases. The mirror effect occurs at decisions 76 and 77 under S2_LOW (Section R.E).

Total Express Lane traffic and its price-responsive component (1,800–4,500 s). A = all vehicles at the first EL detector station of each segment (priced and unpriced); B = toll transactions at decisions whose managed route uses the segment; B/A is an indicator of the price-responsive component (a vehicle can be counted at more than one decision, so B/A can exceed 100% on individual segments).

Table 75. Toll-Bound Pricing: Total and Price-Responsive Express Lane Traffic (1,800-4,500 s)

Measure	Dir.	S2_LOW	S1	S2_HIGH	LOW vs S1	HIGH vs S1
A – total EL vehicles (veh-segments)	EB	3,854.4	3,741.2	3,556.2	+3.02%*	-4.95%*
B – price-responsive transactions (veh-segments)	EB	1,249.3	1,134.5	951.1	+10.12%*	-16.17%*
B/A – price-responsive indicator (%)	EB	32.4	30.3	26.7	+6.89%*	-11.80%*
A – total EL vehicles (veh-segments)	WB	2,958.8	2,697.2	2,278.2	+9.70%*	-15.54%*
B – price-responsive transactions (veh-segments)	WB	2,470.2	2,245.3	1,853.2	+10.01%*	-17.46%*
B/A – price-responsive indicator (%)	WB	83.5	83.3	81.4	+0.27%	-2.25%*
EL section throughput, sum of sections (veh-sections/h, analysis hour)	EB	5,132.3	4,984.1	4,733.8	+2.97%*	-5.02%*

Table 75. Toll-Bound Pricing: Total and Price-Responsive Express Lane Traffic (1,800-4,500 s) (continued)

Measure	Dir.	S2_LOW	S1	S2_HIGH	LOW vs S1	HIGH vs S1
EL section throughput, sum of sections (veh-sections/h, analysis hour)	WB	3,947.5	3,600.9	3,046.7	+9.62%*	-15.39%*
EL vehicle-miles travelled, all EL links (veh-mi, analysis hour)	Both	40,339	38,260	35,000	+5.43%*	-8.52%*

Source: `S2_LOW_S1_S2_HIGH_FINAL_COMPARISON.csv`.

Total EL use moved in the same direction as price-responsive use but by a smaller percentage, because the unpriced flows do not respond to the toll. Per-segment values, including Segment 8 (no price-responsive component), are given in Section R.E.

R.7 Revenue and Price Elasticity

Table 76. Toll-Bound Pricing: Average Toll Paid, Toll Transactions and Revenue by Scenario

Scenario	Average toll paid ($)	Toll transactions (veh)	Revenue ($)	Δ revenue ($)	Δ revenue (%)	95% CI of Δ ($)	Seeds with same sign	p (t / Wilcoxon)
S2_LOW	0.9397 → 0.7193	3,160.4 → 3,441.6	2,969.60 → 2,475.26	-494.34	-16.65%	[-506.04, -482.65]	12/12 (lower)	<0.001 / <0.001
S2_HIGH	0.9397 → 1.3125	3,160.4 → 2,691.1	2,969.60 → 3,532.12	+562.52	+18.94%	[+534.48, +590.55]	12/12 (higher)	<0.001 / <0.001

S1 → scenario, 12-seed means for 0–4,500 s; Δ = mean paired difference from S1.

Source: `S1_vs_S2_LOW_PAIRED_METRICS.csv`; `S1_vs_S2_HIGH_PAIRED_METRICS.csv`.

Decomposition of the revenue change (12-seed means): price effect = (Δ average toll paid) × S1 transactions; volume effect = S1 average toll paid × (Δ transactions); interaction = product of the two changes.

Table 77. Toll-Bound Pricing: Decomposition of the Revenue Change

Scenario	Revenue change ($)	Price effect ($)	Volume effect ($)	Interaction ($)
S2_LOW	-494.34	-696.56	+264.19	-61.97
S2_HIGH	+562.52	+1,178.53	-441.00	-175.02

Source: `S2_HIGH_12RUN_FINAL_VALIDATION.txt`.

Approximate price elasticity. Midpoint (arc) elasticity of total toll transactions with respect to price, computed from 12-seed means, with a bootstrap 95% confidence interval over seed pairs:

Table 78. Toll-Bound Pricing: Approximate Price Elasticity of Toll Transactions

Scenario	Price measure	Price S1 → scenario ($)	Arc elasticity	Bootstrap 95% CI
S2_LOW	Average toll paid	0.9396 → 0.7192	-0.321	[-0.332, -0.310]
S2_LOW	S1-transaction-weighted toll in force	0.9399 → 0.6982	-0.289	[-0.299, -0.278]
S2_HIGH	Average toll paid	0.9396 → 1.3125	-0.484	[-0.505, -0.466]
S2_HIGH	S1-transaction-weighted toll in force	0.9399 → 1.4012	-0.407	[-0.427, -0.390]

The average-toll-paid price used for the elasticity is a ratio of 12-seed means (mean revenue ÷ mean transactions; S1 $0.9396). It differs by at most $0.0001 from the 12-seed mean of the per-seed average toll paid shown in the revenue table above (S1 $0.9397).

Source: `S2_LOW_PRICE_RESPONSE_BY_FACILITY.csv`; `S2_HIGH_PRICE_RESPONSE_BY_FACILITY.csv`.

Demand was inelastic over the tested price range (|E| < 1): -0.32 for the reduction and -0.48 for the increase with respect to the average toll paid. Because the percentage change in transactions is smaller than the percentage change in the toll paid, revenue moves in the same direction as the price: the S2_HIGH price increase more than offsets the loss of transactions, and the S2_LOW price reduction loses more revenue than the additional transactions recover. The elasticities are approximate: tolls are partly endogenous (LOS bands follow density), transactions count managed-lane decisions rather than unique trips, the average toll paid also reflects the mix of facilities used, and only price-responsive SOV traffic is included. The fixed-weight measure, which holds the facility mix at S1 transaction weights, gives smaller magnitudes (-0.29 and -0.41) and the same conclusion.

Revenue by direction (dollars, 0–4,500 s):

Table 79. Toll-Bound Pricing: Toll Revenue by Direction (0-4,500 s)

Direction	S2_LOW	S1	S2_HIGH	LOW vs S1	HIGH vs S1
EB	684.46	760.20	823.58	-9.96%*	+8.34%*
WB	1,790.80	2,209.40	2,708.54	-18.95%*	+22.59%*

Source: `S2_LOW_S1_S2_HIGH_FINAL_COMPARISON.csv`.

R.8 Express Lane Operational Performance

Table 80. Toll-Bound Pricing: Express Lane Operational Performance (Analysis Hour)

Measure (analysis hour 1,800–5,400 s)	S2_LOW	S1	S2_HIGH	LOW vs S1	HIGH vs S1
EL section throughput, EB (veh-sections/h)	5,132.3	4,984.1	4,733.8	+2.97%*	-5.02%*
EL space-mean speed, EB (mph)	67.00	67.17	67.30	-0.25%*	+0.19%*
EL travel time, EB – sum of section means (s)	554.81	553.80	553.13	+0.18%*	-0.12%
EL section throughput, WB (veh-sections/h)	3,947.5	3,600.9	3,046.7	+9.62%*	-15.39%*
EL space-mean speed, WB (mph)	70.54	70.65	70.85	-0.15%	+0.29%*
EL travel time, WB – sum of section means (s)	755.49	754.56	752.66	+0.12%	-0.25%*
EL vehicle-hours of delay, all EL links (veh-h)	21.19	19.69	17.65	+7.61%*	-10.37%*
EL delay per vehicle-mile, all EL links (s/veh-mi)	1.89	1.85	1.82	+2.08%	-2.00%*

Source: `S2_LOW_S1_S2_HIGH_FINAL_COMPARISON.csv`.

Mean EL density by pricing segment (veh/mi/ln, analysis hour; same density formula as the toll controller):

Table 81. Toll-Bound Pricing: Mean Express Lane Density by Pricing Segment

Segment	Dir.	Location	S2_LOW	S1	S2_HIGH	LOW vs S1	HIGH vs S1
1	EB	EB Lake Mary - 417 Eg	13.58	13.35	12.83	+1.76%*	-3.84%*
2	EB	EB 417 Eg - 417 In	9.27	9.01	8.52	+2.83%*	-5.46%*
3	EB	EB 417 In - Dirksen	11.24	10.64	9.77	+5.60%*	-8.18%*
4	EB	EB Dirksen - OCR	4.33	4.26	4.17	+1.70%*	-2.07%*
5	WB	WB OCR - Dirksen	4.39	3.74	2.79	+17.33%*	-25.33%*
6	WB	WB Dirksen - 417	6.58	5.90	4.79	+11.62%*	-18.77%*

Table 81. Toll-Bound Pricing: Mean Express Lane Density by Pricing Segment (continued)

Segment	Dir.	Location	S2_LOW	S1	S2_HIGH	LOW vs S1	HIGH vs S1
7	WB	WB 417 - 46A	4.27	3.92	3.33	+8.69%*	-15.04%*
8	WB	WB 46A - Lake Mary	1.39	1.39	1.40	+0.35%	+0.57%*
9	WB	WB Lake Mary - I-4	11.33	10.53	9.20	+7.65%*	-12.62%*

Source: `S2_LOW_S1_S2_HIGH_FINAL_COMPARISON.csv`.

S2_LOW increased EL utilisation and density (largest density increase +17.33% on Segment 5); S2_HIGH decreased them (largest density decrease -25.33% on Segment 5). EL speeds changed very little because the facility remained uncongested: the largest change in any EL section speed was 0.38% under S2_LOW and 0.38% under S2_HIGH, directional analysis-hour EL speeds stayed between 67.00 and 70.85 mph, and EL section speeds between 66.12 and 71.52 mph in all three scenarios. No segment reached LOS C (Section R.5). The EL delay measures respond in percentage terms (vehicle-hours of delay +7.61% and -10.37%) because the base values are small: delay per vehicle-mile on the EL links was 1.85 s in S1. These changes do not alter the uncongested operating regime of the Express Lanes.

R.9 General-Purpose Lane Operational Performance

Table 82. Toll-Bound Pricing: GP Lane Operational Performance (Analysis Hour)

Measure (analysis hour)	S2_LOW	S1	S2_HIGH	LOW vs S1	HIGH vs S1
GP SOV volume per count station, EB (veh/h)	4,956.4	4,983.4	5,017.3	-0.54%*	+0.68%*
GP space-mean speed, EB sections (mph)	60.94	61.14	60.85	-0.34%	-0.47%
GP travel time, EB – sum of section means, all vehicles (s)	1,153.56	1,151.72	1,155.18	+0.16%	+0.30%
GP SOV volume per count station, WB (veh/h)	5,070.6	5,139.8	5,249.5	-1.35%*	+2.13%*
GP space-mean speed, WB sections (mph)	67.48	67.37	67.21	+0.15%*	-0.23%*
GP travel time, WB – sum of section means, all vehicles (s)	1,048.90	1,050.07	1,051.95	-0.11%*	+0.18%*

GP evaluation sections (analysis hour):

Table 83. Toll-Bound Pricing: GP Evaluation Section Results (Analysis Hour)

Section	Measure	S2_LOW	S1	S2_HIGH	LOW vs S1	HIGH vs S1
101	Volume (veh/h)	516.3	530.0	553.6	-2.58%*	+4.45%*
101	Speed (mph)	64.00	63.94	63.95	+0.08%	+0.02%
101	Travel time, all vehicles (s)	597.69	598.18	598.08	-0.08%	-0.02%
101	Travel time, SOV (s)	596.89	597.36	597.29	-0.08%	-0.01%
101	Delay per vehicle (s/veh)	45.55	45.79	45.96	-0.52%	+0.38%
102	Volume (veh/h)	2,101.7	2,125.1	2,151.8	-1.10%*	+1.25%*
102	Speed (mph)	60.14	60.39	60.00	-0.42%	-0.64%
102	Travel time, all vehicles (s)	555.87	553.53	557.10	+0.42%	+0.64%
102	Travel time, SOV (s)	555.18	552.86	556.41	+0.42%	+0.64%
102	Delay per vehicle (s/veh)	73.75	71.30	75.00	+3.45%	+5.19%
201	Volume (veh/h)	3,228.2	3,305.5	3,442.9	-2.34%*	+4.16%*
201	Speed (mph)	67.17	67.05	66.87	+0.18%*	-0.27%*
201	Travel time, all vehicles (s)	486.97	487.82	489.14	-0.18%*	+0.27%*
201	Travel time, SOV (s)	486.56	487.42	488.74	-0.18%*	+0.27%*
201	Delay per vehicle (s/veh)	29.30	30.12	31.53	-2.74%*	+4.67%*
202	Volume (veh/h)	712.8	726.8	757.0	-1.93%*	+4.16%*
202	Speed (mph)	68.66	68.62	68.56	+0.06%*	-0.10%*
202	Travel time, all vehicles (s)	561.93	562.25	562.81	-0.06%*	+0.10%*
202	Travel time, SOV (s)	561.38	561.67	562.23	-0.05%*	+0.10%*
202	Delay per vehicle (s/veh)	22.43	22.50	23.30	-0.32%	+3.56%*

Source: `S2_LOW_S1_S2_HIGH_FINAL_COMPARISON.csv`.

Lower tolls moved some passenger traffic from the GP lanes to the Express Lanes and higher tolls moved some back (GP SOV volume per count station -0.54% EB and -1.35% WB under S2_LOW; +0.68% EB and +2.13% WB under S2_HIGH). The magnitude is small relative to total GP demand. The largest change in GP section travel time (all vehicles) was 0.42% under S2_LOW (Section 102) and 0.64% under S2_HIGH (Section 102); the largest SOV travel-time change was 0.42% and 0.64%. Several of these changes are statistically detectable – notably the WB sections, where the paired differences are very consistent across seeds – but all are below the 2% practical threshold. At 15-minute resolution the largest directional GP travel-time change was +0.44% under S2_LOW (GP EB (101+102), 4500-5400 s) and +0.80% under S2_HIGH (GP EB (101+102), 4500-5400 s).

Source: `S1_vs_S2_LOW_EL_GP_OPERATIONAL_COMPARISON.csv; S1_vs_S2_HIGH_EL_GP_OPERATIONAL_COMPARISON.csv`.

R.10 Freight and Heavy-Duty Vehicle Operational Impacts

Heavy goods vehicles (HGV, vehicle class 20) do not use the Express Lanes (Section R.11) and do not face a managed-lane decision. The freight question is therefore indirect: **do pricing-induced shifts of passenger traffic between the Express Lanes and the GP lanes improve or worsen the operating conditions experienced by trucks that remain in the GP lanes?** Freight performance is measured on the four GP travel-time sections 101 (EB, SR 434 – US 17), 102 (EB, US 17 – SR 472), 201 (WB, SR 472 – US 17) and 202 (WB, US 17 – SR 434), using HGV class-specific aggregated travel times for means and the raw HGV travel-time records (1,800–5,400 s) for distributions.

Table 84. Toll-Bound Pricing: HGV Counts and Mean Travel Time by GP Section (Analysis Hour)

Section	Measure (analysis hour)	S2_LOW	S1	S2_HIGH	LOW vs S1	HIGH vs S1
101	HGV count (veh/h)	17.9	17.9	17.9	+0.00%	+0.00%
101	Mean HGV travel time (s)	620.17	621.96	621.94	-0.29%*	-0.00%
101	HGV space-mean speed (mph)	61.68	61.50	61.51	+0.29%*	+0.00%
101	HGV delay per vehicle (s/veh)	77.51	79.32	79.31	-2.28%*	-0.02%
102	HGV count (veh/h)	63.2	63.2	62.7	+0.00%	-0.92%*
102	Mean HGV travel time (s)	578.31	575.53	580.39	+0.48%	+0.84%*
102	HGV space-mean speed (mph)	57.81	58.09	57.60	-0.49%	-0.83%*
102	HGV delay per vehicle (s/veh)	92.33	89.45	94.61	+3.21%	+5.76%*
201	HGV count (veh/h)	103.1	103.1	103.1	+0.00%	+0.00%
201	Mean HGV travel time (s)	499.26	500.51	502.19	-0.25%*	+0.34%*
201	HGV space-mean speed (mph)	65.52	65.36	65.14	+0.25%*	-0.33%*
201	HGV delay per vehicle (s/veh)	37.41	38.66	40.30	-3.25%*	+4.24%*
202	HGV count (veh/h)	24.1	24.0	24.3	+0.35%	+1.39%
202	Mean HGV travel time (s)	577.73	579.39	580.15	-0.28%	+0.13%

Table 84. Toll-Bound Pricing: HGV Counts and Mean Travel Time by GP Section (Analysis Hour) (continued)

Section	Measure (analysis hour)	S2_LOW	S1	S2_HIGH	LOW vs S1	HIGH vs S1
202	HGV space-mean speed (mph)	66.79	66.60	66.51	+0.29%	-0.13%
202	HGV delay per vehicle (s/veh)	40.76	42.35	43.48	-3.74%	+2.69%

Source: `S2_LOW_S1_S2_HIGH_FINAL_COMPARISON.csv`.

Paired differences in mean HGV travel time (scenario − S1, 12 seeds, analysis hour):

Table 85. Toll-Bound Pricing: Paired Differences in Mean HGV Travel Time by Section

Section	Scenario	Δ (s)	Δ (%)	95% CI of Δ (s)	p (t)	p (Wilcoxon)	d_z	Classification
101	S2_LOW	-1.79	-0.29%	[-3.44, -0.14]	0.036	0.042	-0.69	statistically significant, below practical threshold (favorable)
101	S2_HIGH	-0.02	-0.00%	[-2.06, +2.03]	0.986	0.910	-0.01	negligible (not significant; 95% CI inside practical threshold)
102	S2_LOW	+2.78	+0.48%	[-2.08, +7.65]	0.234	0.339	+0.36	negligible (not significant; 95% CI inside practical threshold)
102	S2_HIGH	+4.86	+0.84%	[+0.33, +9.39]	0.038	0.034	+0.68	statistically significant, below practical threshold (unfavorable)
201	S2_LOW	-1.25	-0.25%	[-2.12, -0.38]	0.009	0.009	-0.91	statistically significant, below practical threshold (favorable)
201	S2_HIGH	+1.68	+0.34%	[+0.68, +2.68]	0.004	0.002	+1.07	statistically significant, below practical threshold (unfavorable)

Table 85. Toll-Bound Pricing: Paired Differences in Mean HGV Travel Time by Section (continued)

Section	Scenario	Δ (s)	Δ (%)	95% CI of Δ (s)	p (t)	p (Wilcoxon)	d_z	Classification
202	S2_LOW	-1.65	-0.28%	[-3.78, +0.48]	0.116	0.064	-0.49	negligible (not significant; 95% CI inside practical threshold)
202	S2_HIGH	+0.77	+0.13%	[-0.74, +2.27]	0.287	0.301	+0.32	negligible (not significant; 95% CI inside practical threshold)

Source: `S1_vs_S2_LOW_PAIRED_METRICS.csv`; `S1_vs_S2_HIGH_PAIRED_METRICS.csv`.

The largest change in mean HGV travel time was 0.48% under S2_LOW (Section 102) and 0.84% under S2_HIGH (Section 102). Section-level HGV changes were mixed in sign and size: 4 of the 8 section comparisons were statistically detectable (absolute differences of 1.3–4.9 s, made detectable by the consistency of the paired runs), the others were within run-to-run variation, and none approached the 2% practical threshold. HGV counts on the sections were essentially unchanged (largest change 1.39%), as expected for a pricing change that applies only to SOVs.

Travel-time reliability (pooled across 12 seeds). Reliability statistics are computed only where the pooled sample supports them: mean and standard deviation require at least 30 pooled HGV observations; the 95th-percentile travel time (P95), buffer index (BI = (P95 − mean) / mean) and planning time index (PTI = P95 / free-flow travel time) require at least 100. By the established project rule, sections 101 and 202 use hourly reliability only (15-minute P95/BI/PTI are not supported by their small per-interval samples), and sections 102 and 201 support both hourly and pooled 15-minute reliability. The PTI uses the S1 free-flow reference (median HGV travel time at desired speed) for all three scenarios.

Pooled hourly HGV reliability (S2_LOW / S1 / S2_HIGH; travel times in seconds):

Table 86. Toll-Bound Pricing: Pooled Hourly HGV Reliability by Section

Section	Pooled n	Mean (s)	SD (s)	P95 (s)	Buffer index	Planning time index
101	215 / 215 / 215	620.0 / 621.6 / 621.5	26.4 / 27.3 / 26.6	665.3 / 670.1 / 665.6	0.073 / 0.078 / 0.071	1.217 / 1.226 / 1.217
102	759 / 759 / 752	578.0 / 574.9 / 579.9	41.1 / 40.2 / 42.8	657.7 / 648.7 / 656.2	0.138 / 0.128 / 0.132	1.345 / 1.326 / 1.342
201	1237 / 1237 / 1237	499.2 / 500.5 / 502.2	16.2 / 16.3 / 16.4	528.1 / 529.6 / 532.3	0.058 / 0.058 / 0.060	1.136 / 1.139 / 1.145
202	289 / 288 / 292	577.5 / 579.1 / 580.0	19.2 / 19.1 / 19.9	613.6 / 612.7 / 617.0	0.062 / 0.058 / 0.064	1.117 / 1.115 / 1.123

Change in pooled hourly HGV P95 and buffer index (scenario − S1, bootstrap 95% CI over seed pairs):

Table 87. Toll-Bound Pricing: Change in Pooled Hourly HGV 95th-Percentile Travel Time and Buffer Index

Section	Scenario	Δ P95 (s)	95% CI (s)	P95 classification	Δ BI	95% CI	BI classification
101	S2_LOW	-4.76	[-13.30, +8.78]	negligible (not significant; 95% CI inside practical threshold)	-0.0048	[-0.0187, +0.0160]	negligible (not significant; 95% CI inside practical threshold)
101	S2_HIGH	-4.49	[-8.57, +8.18]	negligible (not significant; 95% CI inside practical threshold)	-0.0070	[-0.0142, +0.0125]	negligible (not significant; 95% CI inside practical threshold)
102	S2_LOW	+9.02	[-5.30, +19.57]	directionally unfavorable but not significant	+0.0095	[-0.0126, +0.0216]	directionally unfavorable but not significant
102	S2_HIGH	+7.54	[-7.24, +18.50]	directionally unfavorable but not significant	+0.0032	[-0.0192, +0.0200]	negligible (not significant; 95% CI inside practical threshold)
201	S2_LOW	-1.46	[-4.02, +1.20]	negligible (not significant; 95% CI inside practical threshold)	-0.0002	[-0.0051, +0.0051]	negligible (not significant; 95% CI inside practical threshold)
201	S2_HIGH	+2.72	[-1.29, +6.12]	negligible (not significant; 95% CI inside practical threshold)	+0.0018	[-0.0053, +0.0081]	negligible (not significant; 95% CI inside practical threshold)
202	S2_LOW	+0.85	[-3.91, +5.05]	negligible (not significant; 95% CI inside practical threshold)	+0.0043	[-0.0010, +0.0101]	negligible (not significant; 95% CI inside practical threshold)
202	S2_HIGH	+4.27	[-2.17, +9.75]	negligible (not significant; 95% CI inside practical threshold)	+0.0057	[-0.0035, +0.0140]	negligible (not significant; 95% CI inside practical threshold)

Source: `S1_vs_S2_LOW_HGV_RELIABILITY.csv`; `S1_vs_S2_HIGH_HGV_RELIABILITY.csv`.

Hourly pooled HGV P95 and buffer index showed no statistically significant change on any section under either pricing scenario (every bootstrap interval includes zero). In the pooled 15-minute analysis (supported on sections 102 and 201 only), 3 interval comparisons were statistically detectable: Section 201, 4500-5400 s, S2_LOW P95 -3.73 s (-0.7%); Section 201, 1800-2700 s, S2_HIGH P95 +4.57 s (+0.9%); Section 201, 2700-3600 s, S2_HIGH P95 +5.29 s (+1.0%) – all below the practical threshold. Section-by-section 15-minute results and all reliability cells are given in Sections R.C and R.D.

R.11 HGV Exclusion Validation

Across all validated pricing runs – S1 (13 runs), S2_LOW (12 runs) and S2_HIGH (13 runs, including the duplicate seed-2222 run) – the number of HGV observations was **0 / 0 / 0** at all 178 Express Lane detectors, on the EL travel-time sections 501–509 (aggregated class-20 results and raw HGV records) and on the Express Lane link segments. The 177 class-20 lane restrictions are identical in all scenarios. This confirms that freight impacts are measured on the GP facilities, as intended.

Source: *S1_ANALYSIS_12RUN_FINAL_VALIDATION.txt; S2_LOW_12RUN_FINAL_VALIDATION.txt; S2_HIGH_12RUN_FINAL_VALIDATION.txt.*

R.12 Statistical Significance versus Practical Significance

Statistical significance and practical significance answer different questions and are reported separately.

- **Statistically significant** – the paired difference is unlikely to be due to run-to-run (stochastic) variation: paired t-test $p < 0.05$; results marked * are also significant under the exact Wilcoxon signed-rank test. For pooled reliability, the bootstrap 95% confidence interval excludes zero.
- **Practically meaningful** – the magnitude of the change is large enough to matter operationally, judged against project analytical screening thresholds:

Table 88. Toll-Bound Pricing: Practical-Significance Thresholds of the Toll-Bound Analysis

Measure type	Practical-significance threshold
Travel time and speed	2%
Volumes, transactions, shares, tolls and revenue	5%
Delay	10%
HGV P95 travel time and planning time index	2%
HGV buffer index	0.02 (absolute)

These thresholds are project-defined analytical thresholds and are not FDOT standards.

Results are classified as: *statistically significant and practically meaningful*; *statistically significant but below the practical threshold*; *directionally favourable or unfavourable but not*

significant (confidence interval wider than the threshold); or *negligible* (not significant, and the 95% confidence interval lies entirely inside ± the threshold).

Because every scenario uses the same 12 random seeds, much of the stochastic variation cancels in the paired differences. Very small but consistent differences can therefore be statistically detectable – for example, the WB GP travel-time changes of -0.11% (S2_LOW) and +0.18% (S2_HIGH). Such results are real in the model but operationally negligible, because their magnitudes are well below the practical thresholds. Conversely, delay measures with very small base values (S1 EL section delays of 0.24–8.33 s per vehicle) can exceed the 10% delay threshold with changes of a fraction of a second; these are read together with the absolute values.

R.13 Three-Way Comparison

Table 89. Toll-Bound Pricing: Three-Way Comparison of S2_LOW, S1 and S2_HIGH

Metric	S2_LOW	S1	S2_HIGH	LOW vs S1	HIGH vs S1	Interpretation
Average toll paid per transaction ($)	0.7193	0.9397	1.3125	-23.45%*	+39.68%*	Clear monotonic response; practically meaningful
Toll transactions, all decisions (veh, 0–4,500 s)	3,441.6	3,160.4	2,691.1	+8.90%*	-14.85%*	Clear monotonic response; practically meaningful
Toll revenue, all decisions ($, 0–4,500 s)	2,475.26	2,969.60	3,532.12	-16.65%*	+18.94%*	Clear monotonic response; practically meaningful
EL share at managed-lane decisions (%)	20.47	18.40	15.04	+11.25%*	-18.28%*	Clear monotonic response; practically meaningful
Total EL throughput, EB (veh-sections/h)	5,132.3	4,984.1	4,733.8	+2.97%*	-5.02%*	Clear monotonic response; practically meaningful
Total EL throughput, WB (veh-sections/h)	3,947.5	3,600.9	3,046.7	+9.62%*	-15.39%*	Clear monotonic response; practically meaningful
EL speed, EB (mph)	67.00	67.17	67.30	-0.25%*	+0.19%*	Monotonic and statistically detectable; below practical threshold

Table 89. Toll-Bound Pricing: Three-Way Comparison of S2_LOW, S1 and S2_HIGH (continued)

Metric	S2_LOW	S1	S2_HIGH	LOW vs S1	HIGH vs S1	Interpretation
EL speed, WB (mph)	70.54	70.65	70.85	-0.15%	+0.29%*	Detectable under S2_HIGH only; below practical threshold
GP car (SOV) volume per count station, EB (veh/h)	4,956.4	4,983.4	5,017.3	-0.54%*	+0.68%*	Monotonic and statistically detectable; below practical threshold
GP car (SOV) volume per count station, WB (veh/h)	5,070.6	5,139.8	5,249.5	-1.35%*	+2.13%*	Monotonic and statistically detectable; below practical threshold
GP travel time, EB, all vehicles (s)	1,153.56	1,151.72	1,155.18	+0.16%	+0.30%	Not significant in either scenario (within run-to-run variation)
GP travel time, WB, all vehicles (s)	1,048.90	1,050.07	1,051.95	-0.11%*	+0.18%*	Monotonic and statistically detectable; below practical threshold
Mean HGV travel time, Section 101 (s)	620.17	621.96	621.94	-0.29%*	-0.00%	Detectable under S2_LOW only; below practical threshold
Mean HGV travel time, Section 102 (s)	578.31	575.53	580.39	+0.48%	+0.84%*	Detectable under S2_HIGH only; below practical threshold
Mean HGV travel time, Section 201 (s)	499.26	500.51	502.19	-0.25%*	+0.34%*	Monotonic and statistically detectable; below practical threshold
Mean HGV travel time, Section 202 (s)	577.73	579.39	580.15	-0.28%	+0.13%	Not significant in either scenario (within run-to-run variation)
HGV P95 travel time, Section 101 (s, pooled hourly)	665.3	670.1	665.6	-0.71%	-0.67%	Not significant in either scenario (bootstrap CI includes zero)

Table 89. Toll-Bound Pricing: Three-Way Comparison of S2_LOW, S1 and S2_HIGH (continued)

Metric	S2_LOW	S1	S2_HIGH	LOW vs S1	HIGH vs S1	Interpretation
HGV P95 travel time, Section 102 (s, pooled hourly)	657.7	648.7	656.2	+1.39%	+1.16%	Not significant in either scenario (bootstrap CI includes zero)
HGV P95 travel time, Section 201 (s, pooled hourly)	528.1	529.6	532.3	-0.28%	+0.51%	Not significant in either scenario (bootstrap CI includes zero)
HGV P95 travel time, Section 202 (s, pooled hourly)	613.6	612.7	617.0	+0.14%	+0.70%	Not significant in either scenario (bootstrap CI includes zero)
HGV buffer index, Section 101 (pooled hourly)	0.073	0.078	0.071	-6.28%	-8.97%	Not significant in either scenario (bootstrap CI includes zero)
HGV buffer index, Section 102 (pooled hourly)	0.138	0.128	0.132	+7.40%	+2.49%	Not significant in either scenario (bootstrap CI includes zero)
HGV buffer index, Section 201 (pooled hourly)	0.058	0.058	0.060	-0.34%	+3.27%	Not significant in either scenario (bootstrap CI includes zero)
HGV buffer index, Section 202 (pooled hourly)	0.062	0.058	0.064	+7.40%	+9.98%	Not significant in either scenario (bootstrap CI includes zero)

12-seed means (pooled values for reliability). = significant under the paired t-test and the exact Wilcoxon test ($p < 0.05$); † = bootstrap 95% CI excludes zero (none occurred). "Monotonic" = S2_LOW and S2_HIGH differ significantly from S1 in opposite directions.*

Source: `S2_LOW_S1_S2_HIGH_FINAL_COMPARISON.csv;` `S2_LOW_S1_S2_HIGH_TASK42_SUMMARY_TABLE.csv;` `S1_vs_S2_LOW_HGV_RELIABILITY.csv;` `S1_vs_S2_HIGH_HGV_RELIABILITY.csv`.

Note: the pooled-reliability bootstrap was repeated in the three-way summary file with a different random-number stream; the S2_LOW confidence bounds there differ from the approved S2_LOW reliability file only in the second or third significant figure and lead to the same classifications. This report uses the scenario-specific reliability files.

R.14 Monotonicity and Policy Response

Each metric was classified by whether S2_LOW and S2_HIGH differ significantly from S1 in opposite directions (a monotonic response across LOW → S1 → HIGH):

Table 90. Toll-Bound Pricing: Monotonicity Classification of Metrics

Response class	Metrics
Clear monotonic response, practically meaningful	Average toll paid, Toll transactions, Toll revenue, EL share at decisions, VehML, EL throughput EB, EL throughput WB, EL vehicle-miles travelled, EL density Seg 2, EL density Seg 3, EL density Seg 5, EL density Seg 6, EL density Seg 7, EL density Seg 9, EL vehicle-hours of delay
Monotonic and statistically detectable, below practical threshold	VehGPL, EL density Seg 1, EL density Seg 4, EL speed EB, GP car volume EB, GP car volume WB, GP speed WB, GP travel time WB, GP SOV travel time 201, GP SOV travel time 202, HGV travel time 201
Detectable in one scenario only (small)	EL density Seg 8, EL speed WB, HGV travel time 101, HGV travel time 102
Not significant in either scenario	GP speed EB, GP travel time EB, GP SOV travel time 101, GP SOV travel time 102, HGV travel time 202, Network delay per vehicle (HGV), Network delay per vehicle (all vehicles)
Pooled HGV P95 and buffer index (all four sections)	Not significant in either scenario

Source: `S2_LOW_S1_S2_HIGH_FINAL_COMPARISON.csv; S1_vs_S2_LOW_HGV_RELIABILITY.csv; S1_vs_S2_HIGH_HGV_RELIABILITY.csv`.

The pricing-related metrics – average toll paid, toll transactions, EL share, VehML, EL throughput and revenue – show a strong, monotonic and consistent response to the toll level. GP car volume also responds monotonically, but by at most 2.13%, below the 5% practical threshold. EL densities respond monotonically on eight of the nine pricing segments; the exception is Segment 8, which carries no price-responsive traffic. Speed, travel-time and reliability measures are much less responsive: EL speeds move by a few tenths of one percent, GP and HGV travel times move by less than 1%, and several GP and freight measures are not significant in either scenario. This pattern is consistent with the Express Lanes remaining at LOS A/B and with GP directional space-mean speeds of 61.1 mph (EB) and 67.4 mph (WB) in S1 (Section R.9). The response is not symmetric in magnitude: the 50% increase produced larger changes in the pricing-related metrics than the 30% decrease, and the approximate elasticity was larger in magnitude for the increase (-0.48) than for the decrease (-0.32).

R.15 Policy Interpretation

What does changing the toll level accomplish under baseline demand conditions? Within the tested range (0.70× to 1.50× the existing LOS toll bounds), the toll level primarily determines:

1. **Lane choice** – the share of price-responsive SOVs choosing the Express Lanes (20.5% / 18.4% / 15.0% at the managed-lane decisions, S2_LOW / S1 / S2_HIGH);

2. **Toll transactions** (3,442 / 3,160 / 2,691 per 0–4,500 s); and

3. **Revenue** ($2,475 / $2,970 / $3,532 per 0–4,500 s).

Express Lane speed, GP travel time, freight travel time and freight travel-time reliability remain largely insensitive. The likely mechanism is twofold: the volume shifted between the Express Lanes and the GP lanes is small relative to total GP volume (GP car volume per count station changed by at most 2.13%), and the Express Lanes remain at LOS A/B in all scenarios, so adding or removing price-responsive traffic changes EL density but not EL speed. Under these conditions the pricing policy acts as a lane-choice and revenue instrument rather than as an operational-management instrument.

R.16 Freight-Specific Interpretation

Did lower Express Lane tolls create a measurable indirect freight benefit? No. Under S2_LOW the largest change in mean HGV travel time was 0.48% (Section 102); pooled hourly HGV P95 travel time and buffer index did not change significantly on any section.

Did higher Express Lane tolls create a measurable freight penalty? No. Under S2_HIGH the largest change in mean HGV travel time was 0.84% (Section 102); pooled hourly HGV P95 travel time and buffer index did not change significantly on any section.

These findings are not equivalent to stating that pricing had no effect on freight. Small directional and statistically detectable changes occurred on selected sections – for example, mean HGV travel time on Section 201 changed by -0.25% under S2_LOW and +0.34% under S2_HIGH – but their magnitudes remained below the project's practical-significance threshold, the effects were not consistent across all sections, and reliability measures did not materially change. "Measurable" in this report requires a statistically significant change of at least 2% on at least three of the four GP sections, with no section changing significantly in the opposite direction; neither scenario met this criterion for GP or HGV travel time.

Source: `S2_LOW_12RUN_FINAL_VALIDATION.txt`; `S2_HIGH_12RUN_FINAL_VALIDATION.txt`.

R.17 Limitations

- Baseline demand leaves the Express Lanes predominantly at LOS A/B; no segment reached LOS C in any scenario.
- Consequently the dynamic toll controller is only weakly dynamic under these conditions: tolls are set almost entirely by the LOS bounds, and the `delta.csv` increments are clipped.
- Results may differ under higher traffic demand, when Express Lane segments would reach the LOS C–F bands in which the controller produces graded, demand-responsive tolls.

- A substantial share of Express Lane traffic is not price-responsive (EL boundary input, WB arterial ramp, GP routes of decisions 72/75 over Segment 9); total EL traffic therefore responds less than price-responsive traffic.
- MLE quantities (transactions, revenue, VehML, VehGPL) cover 0–4,500 s and do not include the final 15 minutes of the analysis hour.
- Raw freight travel-time results cover the established 1,800–5,400 s analysis period; raw records time-stamped exactly on a 15-minute boundary are ambiguous by one record between adjacent intervals, so hourly totals are used as authoritative.
- Some 15-minute HGV reliability metrics rely on small samples; per the established rule, 15-minute P95/BI/PTI are reported only for Sections 102 and 201.
- Price elasticities are approximate (endogenous tolls, decision-level transactions, facility mix).
- Facilities 57 and 58 are reported according to their actual route geometry (Facility 57 = SR 417 to Dirksen; Facility 58 = SR 417 to OCR); the pre-existing charging swap between them is unchanged in all scenarios.
- The practical-significance thresholds are project-defined analytical thresholds, not FDOT standards.

R.18 Link to Task 4.3

Under baseline demand, pricing primarily affects lane choice and revenue because the Express Lanes do not approach congested operating conditions. Increased-demand sensitivity scenarios (Task 4.3) will test whether stronger congestion activates the dynamic pricing controller – that is, whether Express Lane segments reach the LOS bands in which tolls respond to density – and whether pricing then produces measurable operational or freight effects. No increased-demand results are reported here.

R.19 Conclusions

1. **Pricing changes have strong and consistent effects on Express Lane choice.** Toll transactions changed by +8.90% (S2_LOW) and -14.85% (S2_HIGH), and the EL share at the managed-lane decisions by +11.25% and -18.28%, in the same direction in every seed.

2. **Revenue responds strongly because price-responsive demand is inelastic.** Revenue changed by -16.65% (S2_LOW) and +18.94% (S2_HIGH); approximate arc elasticities were -0.32 and -0.48.

3. **Express Lane operating conditions remain near free flow under all three pricing scenarios.** No segment reached LOS C; directional EL speeds stayed between 67.00 and 70.85 mph and changed by at most 0.38% at section level.

4. **GP effects are small.** GP section travel times changed by at most 0.42% (S2_LOW) and 0.64% (S2_HIGH); some changes are statistically detectable but none is practically meaningful.

5. **Freight travel-time and reliability effects are not practically meaningful.** Mean HGV travel times changed by at most 0.48% (S2_LOW) and 0.84% (S2_HIGH), and pooled hourly HGV P95 and buffer index did not change significantly on any section.

6. **The primary pricing impacts under baseline demand are lane choice and revenue.**

7. **Increased-demand testing is needed** to determine whether pricing becomes operationally important – for Express Lane protection, GP congestion and freight – under stressed conditions.

R.A Scenario Configuration

Table 91. Toll-Bound Pricing: Scenario Configuration (S2_LOW, S1, S2_HIGH)

Item	S2_LOW	S1	S2_HIGH
LOS toll multiplier	0.70×	1.00×	1.50×
mintoll_los ($/mi, LOS A–F)	0.105, 0.105, 0.119, 0.196, 0.462, 1.001	0.15, 0.15, 0.17, 0.28, 0.66, 1.43	0.225, 0.225, 0.255, 0.420, 0.990, 2.145
maxtoll_los ($/mi, LOS A–F)	0.105, 0.112, 0.161, 0.392, 0.966, 1.400	0.15, 0.16, 0.23, 0.56, 1.38, 2.00	0.225, 0.240, 0.345, 0.840, 2.070, 3.000
min_seg_toll ($)	0.25	0.25	0.25
toll_round ($, rounded up)	0.05	0.05	0.05
Toll-update interval (s)	900	900	900
LOS density thresholds (veh/mi/ln)	11 / 18 / 26 / 35 / 45	11 / 18 / 26 / 35 / 45	11 / 18 / 26 / 35 / 45
TollCalc_v7.py, funcs_v7.py, delta.csv	identical to S1	control	identical to S1
Simulation (period / resolution / runs used)	5,400 s / 10 / 12	5,400 s / 10 / 12	5,400 s / 10 / 12
Random seeds	2222–14443 (increment 1,111)	2222–14443 (increment 1,111)	2222–14443 (increment 1,111)

Source: `S2_LOW_12RUN_FINAL_VALIDATION.txt`; `S2_HIGH_12RUN_FINAL_VALIDATION.txt`; `S1_ANALYSIS_12RUN_FINAL_VALIDATION.txt`.

R.B Paired Statistical Results (Key Metrics)

S2_LOW − S1 (n = 12 seed pairs)

Table 92. Toll-Bound Pricing: Paired Statistical Results, S2_LOW vs. S1 (Key Metrics)

Metric	S1 mean	S2_LOW mean	Mean Δ	Δ %	SD of Δ	Median Δ	Min / max Δ	95% CI of Δ	p (t)	p (Wilcoxon)	d_z
Toll transactions, all (veh)	3,160.4	3,441.6	+281.2	+8.90%	23.2	+281.5	+244.0 / +316.0	[+266.4, +295.9]	<0.001	<0.001	+12.12
Average toll paid ($)	0.9397	0.7193	-0.2204	-23.45%	0.0058	-0.2196	-0.2290 / -0.2114	[-0.2241, -0.2167]	<0.001	<0.001	-38.02
Toll revenue ($)	2,969.60	2,475.26	-494.34	-16.65%	18.41	-495.05	-520.05 / -450.60	[-506.04, -482.65]	<0.001	<0.001	-26.85
VehML (veh)	2,559.5	2,835.2	+275.7	+10.77%	9.2	+278.0	+262.0 / +291.0	[+269.8, +281.5]	<0.001	<0.001	+29.81
VehGPL (veh)	11,348.4	11,012.3	-336.1	-2.96%	25.5	-338.0	-366.0 / -272.0	[-352.3, -319.9]	<0.001	<0.001	-13.18

Table 92. Toll-Bound Pricing: Paired Statistical Results, S2_LOW vs. S1 (Key Metrics) (continued)

Metric	S1 mean	S2_LOW mean	Mean Δ	Δ %	SD of Δ	Median Δ	Min / max Δ	95% CI of Δ	p (t)	p (Wilcoxon)	d_z
EL share at decisions	0.1840	0.2047	+0.0207	+11.25%	0.0007	+0.0209	+0.0193 / +0.0216	[+0.0203, +0.0212]	<0.001	<0.001	+29.21
EL throughput EB (veh-sections/h)	4,984.1	5,132.3	+148.2	+2.97%	27.5	+144.5	+113.0 / +190.0	[+130.8, +165.7]	<0.001	<0.001	+5.40
EL throughput WB (veh-sections/h)	3,600.9	3,947.5	+346.6	+9.62%	17.1	+351.5	+309.0 / +367.0	[+335.7, +357.5]	<0.001	<0.001	+20.25
EL speed EB (mph)	67.17	67.00	-0.17	-0.25%	0.16	-0.13	-0.51 / +0.10	[-0.27, -0.07]	0.004	0.005	-1.07
EL speed WB (mph)	70.65	70.54	-0.11	-0.15%	0.15	-0.09	-0.36 / +0.09	[-0.20, -0.01]	0.035	0.064	-0.69
EL travel time EB (s)	553.80	554.81	+1.01	+0.18%	1.14	+0.98	-1.27 / +3.23	[+0.29, +1.74]	0.011	0.009	+0.89
EL travel time WB (s)	754.56	755.49	+0.94	+0.12%	1.59	+0.59	-1.08 / +3.98	[-0.08, +1.95]	0.067	0.092	+0.59
EL vehicle-hours of delay (veh-h)	19.69	21.19	+1.50	+7.61%	0.76	+1.43	+0.33 / +3.23	[+1.02, +1.98]	<0.001	<0.001	+1.98
GP SOV volume per station EB (veh/h)	4,983.4	4,956.4	-27.0	-0.54%	13.8	-27.8	-50.2 / -3.0	[-35.8, -18.2]	<0.001	<0.001	-1.95
GP SOV volume per station WB (veh/h)	5,139.8	5,070.6	-69.2	-1.35%	17.0	-66.5	-99.5 / -45.5	[-80.0, -58.4]	<0.001	<0.001	-4.07
GP speed EB (mph)	61.14	60.94	-0.20	-0.34%	0.64	-0.03	-1.61 / +0.59	[-0.61, +0.20]	0.288	0.339	-0.32
GP speed WB (mph)	67.37	67.48	+0.10	+0.15%	0.06	+0.09	+0.02 / +0.22	[+0.07, +0.14]	<0.001	<0.001	+1.77
GP travel time EB (s)	1,151.72	1,153.56	+1.84	+0.16%	7.72	-1.13	-8.73 / +19.01	[-3.06, +6.75]	0.426	0.569	+0.24
GP travel time WB (s)	1,050.07	1,048.90	-1.18	-0.11%	0.68	-1.08	-2.43 / -0.28	[-1.61, -0.74]	<0.001	<0.001	-1.73
GP SOV travel time 101 (s)	597.36	596.89	-0.47	-0.08%	1.11	-0.29	-2.09 / +0.98	[-1.18, +0.23]	0.169	0.204	-0.42
GP SOV travel time 102 (s)	552.86	555.18	+2.31	+0.42%	7.11	+0.39	-6.56 / +17.75	[-2.20, +6.83]	0.284	0.380	+0.33
GP SOV travel time 201 (s)	487.42	486.56	-0.86	-0.18%	0.51	-0.81	-1.85 / -0.01	[-1.18, -0.53]	<0.001	<0.001	-1.68
GP SOV travel time 202 (s)	561.67	561.38	-0.29	-0.05%	0.45	-0.39	-1.07 / +0.47	[-0.57, -0.003]	0.048	0.042	-0.64

Table 92. Toll-Bound Pricing: Paired Statistical Results, S2_LOW vs. S1 (Key Metrics) (continued)

Metric	S1 mean	S2_LOW mean	Mean Δ	Δ %	SD of Δ	Median Δ	Min / max Δ	95% CI of Δ	p (t)	p (Wilcoxon)	d_z
HGV travel time 101 (s)	621.96	620.17	-1.79	-0.29%	2.60	-1.80	-5.66 / +3.14	[-3.44, -0.14]	0.036	0.042	-0.69
HGV travel time 102 (s)	575.53	578.31	+2.78	+0.48%	7.66	+0.87	-7.28 / +22.33	[-2.08, +7.65]	0.234	0.339	+0.36
HGV travel time 201 (s)	500.51	499.26	-1.25	-0.25%	1.37	-1.26	-3.56 / +0.79	[-2.12, -0.38]	0.009	0.009	-0.91
HGV travel time 202 (s)	579.39	577.73	-1.65	-0.28%	3.35	-1.57	-10.09 / +3.96	[-3.78, +0.48]	0.116	0.064	-0.49
HGV delay per vehicle 101 (s/veh)	79.32	77.51	-1.81	-2.28%	2.53	-1.76	-5.51 / +2.97	[-3.41, -0.20]	0.031	0.042	-0.72
HGV delay per vehicle 102 (s/veh)	89.45	92.33	+2.87	+3.21%	7.34	+1.23	-5.46 / +22.28	[-1.79, +7.53]	0.202	0.301	+0.39
HGV delay per vehicle 201 (s/veh)	38.66	37.41	-1.26	-3.25%	1.39	-1.30	-3.78 / +0.78	[-2.14, -0.37]	0.010	0.012	-0.90
HGV delay per vehicle 202 (s/veh)	42.35	40.76	-1.59	-3.74%	3.53	-1.65	-10.55 / +4.48	[-3.83, +0.66]	0.148	0.092	-0.45
Network delay per vehicle, HGV (s/veh)	111.37	111.50	+0.12	+0.11%	1.73	+0.55	-2.59 / +2.56	[-0.98, +1.22]	0.808	0.791	+0.07
Network delay per vehicle, all (s/veh)	100.15	100.02	-0.13	-0.13%	1.10	+0.18	-1.74 / +1.26	[-0.83, +0.57]	0.694	0.791	-0.12

Source: `S1_vs_S2_LOW_PAIRED_METRICS.csv`.

S2_HIGH − S1 (n = 12 seed pairs)

Table 93. Toll-Bound Pricing: Paired Statistical Results, S2_HIGH vs. S1 (Key Metrics)

Metric	S1 mean	S2_HIGH mean	Mean Δ	Δ %	SD of Δ	Median Δ	Min / max Δ	95% CI of Δ	p (t)	p (Wilcoxon)	d_z
Toll transactions, all (veh)	3,160.4	2,691.1	-469.3	-14.85%	35.0	-459.5	-534.0 / -418.0	[-491.6, -447.1]	<0.001	<0.001	-13.40
Average toll paid ($)	0.9397	1.3125	+0.3729	+39.68%	0.0064	+0.3722	+0.3626 / +0.3808	[+0.3688, +0.3769]	<0.001	<0.001	+58.13

Table 93. Toll-Bound Pricing: Paired Statistical Results, S2_HIGH vs. S1 (Key Metrics) (continued)

Metric	S1 mean	S2_HIGH mean	Mean Δ	Δ %	SD of Δ	Median Δ	Min / max Δ	95% CI of Δ	p (t)	p (Wilcoxon)	d_z
Toll revenue ($)	2,969.60	3,532.12	+562.52	+18.94%	44.13	+568.02	+478.35 / +621.90	[+534.48, +590.55]	<0.001	<0.001	+12.75
VehML (veh)	2,559.5	2,101.8	-457.7	-17.88%	23.8	-455.0	-499.0 / -431.0	[-472.8, -442.6]	<0.001	<0.001	-19.26
VehGPL (veh)	11,348.4	11,874.0	+525.6	+4.63%	31.1	+525.5	+482.0 / +576.0	[+505.8, +545.4]	<0.001	<0.001	+16.89
EL share at decisions	0.1840	0.1504	-0.0336	-18.28%	0.0016	-0.0331	-0.0363 / -0.0314	[-0.0347, -0.0326]	<0.001	<0.001	-20.74
EL throughput EB (veh-sections/h)	4,984.1	4,733.8	-250.2	-5.02%	17.1	-253.0	-281.0 / -217.0	[-261.1, -239.4]	<0.001	<0.001	-14.64
EL throughput WB (veh-sections/h)	3,600.9	3,046.7	-554.2	-15.39%	27.9	-559.5	-604.0 / -508.0	[-572.0, -536.5]	<0.001	<0.001	-19.89
EL speed EB (mph)	67.17	67.30	+0.13	+0.19%	0.16	+0.17	-0.13 / +0.32	[+0.03, +0.23]	0.016	0.027	+0.82
EL speed WB (mph)	70.65	70.85	+0.20	+0.29%	0.19	+0.21	-0.14 / +0.48	[+0.08, +0.32]	0.003	0.002	+1.07
EL travel time EB (s)	553.80	553.13	-0.67	-0.12%	1.17	-0.85	-2.45 / +0.91	[-1.41, +0.07]	0.073	0.077	-0.57
EL travel time WB (s)	754.56	752.66	-1.90	-0.25%	2.22	-1.87	-5.23 / +1.90	[-3.31, -0.49]	0.013	0.027	-0.86
EL vehicle-hours of delay (veh-h)	19.69	17.65	-2.04	-10.37%	0.52	-2.07	-2.99 / -1.10	[-2.37, -1.72]	<0.001	<0.001	-3.97
GP SOV volume per station EB (veh/h)	4,983.4	5,017.3	+33.9	+0.68%	7.4	+34.0	+22.1 / +48.1	[+29.2, +38.6]	<0.001	<0.001	+4.59
GP SOV volume per station WB (veh/h)	5,139.8	5,249.5	+109.7	+2.13%	18.1	+108.2	+86.8 / +144.0	[+98.2, +121.2]	<0.001	<0.001	+6.06
GP speed EB (mph)	61.14	60.85	-0.29	-0.47%	0.52	-0.26	-1.60 / +0.29	[-0.62, +0.04]	0.083	0.077	-0.55
GP speed WB (mph)	67.37	67.21	-0.16	-0.23%	0.07	-0.15	-0.24 / -0.03	[-0.20, -0.12]	<0.001	<0.001	-2.36
GP travel time EB (s)	1,151.72	1,155.18	+3.46	+0.30%	6.08	+3.38	-3.42 / +19.05	[-0.40, +7.33]	0.074	0.052	+0.57
GP travel time WB (s)	1,050.07	1,051.95	+1.87	+0.18%	0.72	+1.80	+0.41 / +2.82	[+1.41, +2.33]	<0.001	<0.001	+2.59
GP SOV travel time 101 (s)	597.36	597.29	-0.06	-0.01%	0.82	-0.15	-1.11 / +1.28	[-0.59, +0.46]	0.792	0.733	-0.08
GP SOV travel time 102 (s)	552.86	556.41	+3.54	+0.64%	5.92	+2.87	-2.93 / +18.02	[-0.22, +7.30]	0.062	0.064	+0.60

Table 93. Toll-Bound Pricing: Paired Statistical Results, S2_HIGH vs. S1 (Key Metrics) (continued)

Metric	S1 mean	S2_HIGH mean	Mean Δ	Δ %	SD of Δ	Median Δ	Min / max Δ	95% CI of Δ	p (t)	p (Wilcoxon)	d_z
GP SOV travel time 201 (s)	487.42	488.74	+1.32	+0.27%	0.58	+1.20	+0.35 / +2.13	[+0.95, +1.69]	<0.001	<0.001	+2.28
GP SOV travel time 202 (s)	561.67	562.23	+0.56	+0.10%	0.47	+0.59	-0.04 / +1.41	[+0.27, +0.86]	0.002	0.002	+1.21
HGV travel time 101 (s)	621.96	621.94	-0.02	-0.00%	3.22	-0.70	-5.12 / +5.57	[-2.06, +2.03]	0.986	0.910	-0.01
HGV travel time 102 (s)	575.53	580.39	+4.86	+0.84%	7.13	+5.00	-3.66 / +20.50	[+0.33, +9.39]	0.038	0.034	+0.68
HGV travel time 201 (s)	500.51	502.19	+1.68	+0.34%	1.57	+1.49	-0.57 / +4.21	[+0.68, +2.68]	0.004	0.002	+1.07
HGV travel time 202 (s)	579.39	580.15	+0.77	+0.13%	2.37	+0.93	-2.91 / +3.40	[-0.74, +2.27]	0.287	0.301	+0.32
HGV delay per vehicle 101 (s/veh)	79.32	79.31	-0.01	-0.02%	3.19	-0.60	-4.97 / +5.47	[-2.04, +2.02]	0.989	0.791	-0.00
HGV delay per vehicle 102 (s/veh)	89.45	94.61	+5.16	+5.76%	7.08	+4.94	-3.89 / +20.52	[+0.66, +9.66]	0.028	0.034	+0.73
HGV delay per vehicle 201 (s/veh)	38.66	40.30	+1.64	+4.24%	1.58	+1.39	-0.73 / +3.93	[+0.64, +2.64]	0.004	0.005	+1.04
HGV delay per vehicle 202 (s/veh)	42.35	43.48	+1.14	+2.69%	3.51	+1.04	-3.17 / +9.53	[-1.09, +3.37]	0.286	0.339	+0.32
Network delay per vehicle, HGV (s/veh)	111.37	112.20	+0.82	+0.74%	1.34	+0.53	-1.09 / +3.28	[-0.03, +1.67]	0.056	0.077	+0.61
Network delay per vehicle, all (s/veh)	100.15	100.69	+0.55	+0.55%	0.87	+0.58	-1.09 / +2.04	[-0.004, +1.10]	0.051	0.042	+0.63

Source: `S1_vs_S2_HIGH_PAIRED_METRICS.csv`.

R.C HGV Section-by-Section Results

S2_LOW − S1: HGV count and mean HGV travel time by section and interval (counts in veh per interval or hour; travel times in s)

Table 94. Toll-Bound Pricing: HGV Count and Mean Travel Time by Section and Interval, S2_LOW vs. S1

Section	Interval (s)	Measure	S1 mean	S2_LOW mean	Mean Δ	Δ %	95% CI of Δ	Pairs	p (t)	p (Wilcoxon)	Classification
101	1800-2700	HGV count	4.08	4.08	0.00	+0.00%	[+0.00, +0.00]	12	1.000	1.000	no change (identical in every seed)
101	1800-2700	HGV mean travel time (s)	601.10	602.05	+0.95	+0.16%	[-3.43, +5.32]	11	0.641	0.206	negligible (not significant; 95% CI inside practical threshold)
101	2700-3600	HGV count	3.42	3.33	-0.08	-2.44%	[-0.27, +0.10]	12	0.339	1.000	not significant (decrease)
101	2700-3600	HGV mean travel time (s)	618.55	615.71	-2.84	-0.46%	[-9.89, +4.22]	12	0.395	0.569	negligible (not significant; 95% CI inside practical threshold)
101	3600-4500	HGV count	5.08	5.17	+0.08	+1.64%	[-0.10, +0.27]	12	0.339	1.000	not significant (increase)
101	3600-4500	HGV mean travel time (s)	635.49	629.24	-6.25	-0.98%	[-11.13, -1.37]	12	0.017	0.016	statistically significant, below practical threshold (favorable)
101	4500-5400	HGV count	5.33	5.33	0.00	+0.00%	[+0.00, +0.00]	12	1.000	1.000	no change (identical in every seed)
101	4500-5400	HGV mean travel time (s)	625.08	625.98	+0.90	+0.14%	[-3.15, +4.95]	12	0.634	0.733	negligible (not significant; 95% CI inside practical threshold)
101	1800-5400 hour	HGV count	17.92	17.92	0.00	+0.00%	[+0.00, +0.00]	12	1.000	1.000	no change (identical in every seed)
101	1800-5400 hour	HGV mean travel time (s)	621.96	620.17	-1.79	-0.29%	[-3.44, -0.14]	12	0.036	0.042	statistically significant, below practical threshold (favorable)
102	1800-2700	HGV count	13.33	13.42	+0.08	+0.62%	[-0.42, +0.59]	12	0.723	1.000	negligible (not significant; 95% CI inside practical threshold)
102	1800-2700	HGV mean travel time (s)	539.19	540.42	+1.23	+0.23%	[-1.47, +3.94]	12	0.337	0.204	negligible (not significant; 95% CI inside practical threshold)
102	2700-3600	HGV count	16.08	16.17	+0.08	+0.52%	[-0.55, +0.72]	12	0.777	1.000	negligible (not significant; 95% CI inside practical threshold)

Table 94. Toll-Bound Pricing: HGV Count and Mean Travel Time by Section and Interval, S2_LOW vs. S1 (continued)

Section	Interval (s)	Measure	S1 mean	S2_LOW mean	Mean Δ	Δ %	95% CI of Δ	Pairs	p (t)	p (Wilcoxon)	Classification
102	2700-3600	HGV mean travel time (s)	553.12	554.56	+1.44	+0.26%	[-1.97, +4.84]	12	0.374	0.470	negligible (not significant; 95% CI inside practical threshold)
102	3600-4500	HGV count	17.33	17.17	-0.17	-0.96%	[-0.62, +0.29]	12	0.438	0.750	negligible (not significant; 95% CI inside practical threshold)
102	3600-4500	HGV mean travel time (s)	586.73	589.89	+3.16	+0.54%	[-3.28, +9.60]	12	0.303	0.470	negligible (not significant; 95% CI inside practical threshold)
102	4500-5400	HGV count	16.50	16.50	0.00	+0.00%	[-0.54, +0.54]	12	1.000	1.000	negligible (not significant; 95% CI inside practical threshold)
102	4500-5400	HGV mean travel time (s)	616.03	622.33	+6.30	+1.02%	[-7.49, +20.09]	12	0.336	0.622	directionally unfavorable but not significant
102	1800-5400 hour	HGV count	63.25	63.25	0.00	+0.00%	[-0.47, +0.47]	12	1.000	1.000	negligible (not significant; 95% CI inside practical threshold)
102	1800-5400 hour	HGV mean travel time (s)	575.53	578.31	+2.79	+0.48%	[-2.08, +7.65]	12	0.234	0.339	negligible (not significant; 95% CI inside practical threshold)
201	1800-2700	HGV count	22.33	22.08	-0.25	-1.12%	[-0.54, +0.04]	12	0.082	0.250	negligible (not significant; 95% CI inside practical threshold)
201	1800-2700	HGV mean travel time (s)	494.80	493.84	-0.95	-0.19%	[-2.41, +0.50]	12	0.177	0.204	negligible (not significant; 95% CI inside practical threshold)
201	2700-3600	HGV count	26.33	26.83	+0.50	+1.90%	[-0.01, +1.01]	12	0.053	0.125	negligible (not significant; 95% CI inside practical threshold)

Table 94. Toll-Bound Pricing: HGV Count and Mean Travel Time by Section and Interval, S2_LOW vs. S1 (continued)

Section	Interval (s)	Measure	S1 mean	S2_LOW mean	Mean Δ	Δ %	95% CI of Δ	Pairs	p (t)	p (Wilcoxon)	Classification
201	2700-3600	HGV mean travel time (s)	500.42	499.91	-0.50	-0.10%	[-2.27, +1.26]	12	0.543	0.677	negligible (not significant; 95% CI inside practical threshold)
201	3600-4500	HGV count	27.58	27.25	-0.33	-1.21%	[-1.16, +0.49]	12	0.394	0.750	negligible (not significant; 95% CI inside practical threshold)
201	3600-4500	HGV mean travel time (s)	505.56	503.90	-1.67	-0.33%	[-3.92, +0.59]	12	0.133	0.233	negligible (not significant; 95% CI inside practical threshold)
201	4500-5400	HGV count	26.83	26.92	+0.08	+0.31%	[-0.66, +0.82]	12	0.809	0.973	negligible (not significant; 95% CI inside practical threshold)
201	4500-5400	HGV mean travel time (s)	499.99	498.40	-1.58	-0.32%	[-3.09, -0.08]	12	0.041	0.092	statistically significant, below practical threshold (favorable)
201	1800-5400 hour	HGV count	103.08	103.08	0.00	+0.00%	[-0.54, +0.54]	12	1.000	1.000	negligible (not significant; 95% CI inside practical threshold)
201	1800-5400 hour	HGV mean travel time (s)	500.51	499.26	-1.25	-0.25%	[-2.12, -0.38]	12	0.009	0.009	statistically significant, below practical threshold (favorable)
202	1800-2700	HGV count	4.92	5.08	+0.17	+3.39%	[-0.08, +0.41]	12	0.166	0.500	not significant (increase)
202	1800-2700	HGV mean travel time (s)	572.05	569.27	-2.77	-0.48%	[-4.91, -0.64]	12	0.015	0.009	statistically significant, below practical threshold (favorable)
202	2700-3600	HGV count	6.75	6.75	0.00	+0.00%	[-0.47, +0.47]	12	1.000	1.000	not significant (no net change)
202	2700-3600	HGV mean travel time (s)	578.32	574.79	-3.53	-0.61%	[-10.73, +3.67]	12	0.304	0.233	negligible (not significant; 95% CI inside practical threshold)
202	3600-4500	HGV count	6.33	6.42	+0.08	+1.32%	[-0.42, +0.59]	12	0.723	1.000	not significant (increase)

Table 94. Toll-Bound Pricing: HGV Count and Mean Travel Time by Section and Interval, S2_LOW vs. S1 (continued)

Section	Interval (s)	Measure	S1 mean	S2_LOW mean	Mean Δ	Δ %	95% CI of Δ	Pairs	p (t)	p (Wilcoxon)	Classification
202	3600-4500	HGV mean travel time (s)	585.63	581.53	-4.10	-0.70%	[-7.81, -0.40]	12	0.033	0.027	statistically significant, below practical threshold (favorable)
202	4500-5400	HGV count	6.00	5.83	-0.17	-2.78%	[-0.53, +0.20]	12	0.339	0.625	not significant (decrease)
202	4500-5400	HGV mean travel time (s)	578.26	581.83	+3.57	+0.62%	[-2.99, +10.13]	12	0.256	0.339	negligible (not significant; 95% CI inside practical threshold)
202	1800-5400 hour	HGV count	24.00	24.08	+0.08	+0.35%	[-0.34, +0.51]	12	0.674	1.000	negligible (not significant; 95% CI inside practical threshold)
202	1800-5400 hour	HGV mean travel time (s)	579.39	577.73	-1.65	-0.28%	[-3.78, +0.48]	12	0.116	0.064	negligible (not significant; 95% CI inside practical threshold)

Pairs < 12 indicate seeds with no HGV observation in that interval in at least one scenario. 15-minute means on Sections 101 and 202 rest on few trucks per seed and are noisy. "No net change" marks a count whose mean paired difference is exactly zero (the source file attaches a direction label to such rows).

Source: `S1_vs_S2_LOW_HGV_TRAVEL_TIME.csv`.

S2_HIGH − S1: HGV count and mean HGV travel time by section and interval (counts in veh per interval or hour; travel times in s)

Table 95. Toll-Bound Pricing: HGV Count and Mean Travel Time by Section and Interval, S2_HIGH vs. S1

Section	Interval (s)	Measure	S1 mean	S2_HIGH mean	Mean Δ	Δ %	95% CI of Δ	Pairs	p (t)	p (Wilcoxon)	Classification
101	1800-2700	HGV count	4.08	4.17	+0.08	+2.04%	[-0.10, +0.27]	12	0.339	1.000	not significant (increase)
101	1800-2700	HGV mean travel time (s)	601.10	601.72	+0.62	+0.10%	[-3.46, +4.69]	11	0.743	0.966	negligible (not significant; 95% CI inside practical threshold)
101	2700-3600	HGV count	3.42	3.17	-0.25	-7.32%	[-0.54, +0.04]	12	0.082	0.250	not significant (decrease)
101	2700-3600	HGV mean travel time (s)	618.55	619.33	+0.79	+0.13%	[-6.53, +8.10]	12	0.817	0.470	negligible (not significant; 95% CI inside practical threshold)
101	3600-4500	HGV count	5.08	5.25	+0.17	+3.28%	[-0.08, +0.41]	12	0.166	0.500	not significant (increase)

Table 95. Toll-Bound Pricing: HGV Count and Mean Travel Time by Section and Interval, S2_HIGH vs. S1 (continued)

Section	Interval (s)	Measure	S1 mean	S2_HIGH mean	Mean Δ	Δ %	95% CI of Δ	Pairs	p (t)	p (Wilcoxon)	Classification
101	3600-4500	HGV mean travel time (s)	635.49	635.81	+0.32	+0.05%	[-6.08, +6.71]	12	0.916	1.000	negligible (not significant; 95% CI inside practical threshold)
101	4500-5400	HGV count	5.33	5.33	0.00	+0.00%	[+0.00, +0.00]	12	1.000	1.000	no change (identical in every seed)
101	4500-5400	HGV mean travel time (s)	625.08	625.50	+0.43	+0.07%	[-4.04, +4.89]	12	0.837	0.970	negligible (not significant; 95% CI inside practical threshold)
101	1800-5400 hour	HGV count	17.92	17.92	0.00	+0.00%	[+0.00, +0.00]	12	1.000	1.000	no change (identical in every seed)
101	1800-5400 hour	HGV mean travel time (s)	621.96	621.94	-0.02	-0.00%	[-2.06, +2.03]	12	0.986	0.910	negligible (not significant; 95% CI inside practical threshold)
102	1800-2700	HGV count	13.33	13.42	+0.08	+0.62%	[-0.60, +0.77]	12	0.795	1.000	not significant (increase)
102	1800-2700	HGV mean travel time (s)	539.19	541.01	+1.81	+0.34%	[-1.43, +5.05]	12	0.244	0.092	negligible (not significant; 95% CI inside practical threshold)
102	2700-3600	HGV count	16.08	16.08	0.00	+0.00%	[-0.90, +0.90]	12	1.000	0.922	not significant (no net change)
102	2700-3600	HGV mean travel time (s)	553.12	554.66	+1.53	+0.28%	[-1.33, +4.40]	12	0.264	0.424	negligible (not significant; 95% CI inside practical threshold)
102	3600-4500	HGV count	17.33	16.75	-0.58	-3.37%	[-1.16, -0.01]	12	0.046	0.094	statistically significant, below practical threshold (decrease)
102	3600-4500	HGV mean travel time (s)	586.73	591.39	+4.66	+0.79%	[-1.27, +10.59]	12	0.112	0.129	negligible (not significant; 95% CI inside practical threshold)
102	4500-5400	HGV count	16.50	16.42	-0.08	-0.51%	[-0.66, +0.49]	12	0.754	1.000	negligible (not significant; 95% CI inside practical threshold)

Table 95. Toll-Bound Pricing: HGV Count and Mean Travel Time by Section and Interval, S2_HIGH vs. S1 (continued)

Section	Interval (s)	Measure	S1 mean	S2_HIGH mean	Mean Δ	Δ %	95% CI of Δ	Pairs	p (t)	p (Wilcoxon)	Classification
102	4500-5400	HGV mean travel time (s)	616.03	626.67	+10.64	+1.73%	[+1.20, +20.09]	12	0.031	0.034	statistically significant, below practical threshold (unfavorable)
102	1800-5400 hour	HGV count	63.25	62.67	-0.58	-0.92%	[-1.01, -0.16]	12	0.012	0.031	statistically significant, below practical threshold (decrease)
102	1800-5400 hour	HGV mean travel time (s)	575.53	580.39	+4.86	+0.84%	[+0.33, +9.39]	12	0.038	0.034	statistically significant, below practical threshold (unfavorable)
201	1800-2700	HGV count	22.33	22.33	0.00	+0.00%	[-0.27, +0.27]	12	1.000	1.000	negligible (not significant; 95% CI inside practical threshold)
201	1800-2700	HGV mean travel time (s)	494.80	496.60	+1.80	+0.36%	[-0.24, +3.85]	12	0.078	0.110	negligible (not significant; 95% CI inside practical threshold)
201	2700-3600	HGV count	26.33	26.50	+0.17	+0.63%	[-0.36, +0.70]	12	0.504	0.750	negligible (not significant; 95% CI inside practical threshold)
201	2700-3600	HGV mean travel time (s)	500.42	502.84	+2.42	+0.48%	[+0.80, +4.05]	12	0.007	0.016	statistically significant, below practical threshold (unfavorable)
201	3600-4500	HGV count	27.58	27.25	-0.33	-1.21%	[-1.07, +0.40]	12	0.339	0.500	negligible (not significant; 95% CI inside practical threshold)
201	3600-4500	HGV mean travel time (s)	505.56	507.33	+1.76	+0.35%	[-1.73, +5.26]	12	0.289	0.380	negligible (not significant; 95% CI inside practical threshold)
201	4500-5400	HGV count	26.83	27.00	+0.17	+0.62%	[-0.54, +0.88]	12	0.615	1.000	negligible (not significant; 95% CI inside practical threshold)

Table 95. Toll-Bound Pricing: HGV Count and Mean Travel Time by Section and Interval, S2_HIGH vs. S1 (continued)

Section	Interval (s)	Measure	S1 mean	S2_HIGH mean	Mean Δ	Δ %	95% CI of Δ	Pairs	p (t)	p (Wilcoxon)	Classification
201	4500-5400	HGV mean travel time (s)	499.99	501.39	+1.41	+0.28%	[-0.29, +3.10]	12	0.095	0.110	negligible (not significant; 95% CI inside practical threshold)
201	1800-5400 hour	HGV count	103.08	103.08	0.00	+0.00%	[-0.66, +0.66]	12	1.000	1.000	negligible (not significant; 95% CI inside practical threshold)
201	1800-5400 hour	HGV mean travel time (s)	500.51	502.19	+1.68	+0.34%	[+0.68, +2.68]	12	0.004	0.002	statistically significant, below practical threshold (unfavorable)
202	1800-2700	HGV count	4.92	5.25	+0.33	+6.78%	[-0.08, +0.75]	12	0.104	0.250	not significant (increase)
202	1800-2700	HGV mean travel time (s)	572.05	568.60	-3.44	-0.60%	[-7.17, +0.29]	12	0.067	0.077	negligible (not significant; 95% CI inside practical threshold)
202	2700-3600	HGV count	6.75	6.58	-0.17	-2.47%	[-0.76, +0.43]	12	0.550	0.750	not significant (decrease)
202	2700-3600	HGV mean travel time (s)	578.32	575.78	-2.54	-0.44%	[-13.43, +8.36]	12	0.618	0.733	directionally favorable but not significant
202	3600-4500	HGV count	6.33	6.42	+0.08	+1.32%	[-0.42, +0.59]	12	0.723	1.000	not significant (increase)
202	3600-4500	HGV mean travel time (s)	585.63	587.27	+1.64	+0.28%	[-1.02, +4.29]	12	0.202	0.233	negligible (not significant; 95% CI inside practical threshold)
202	4500-5400	HGV count	6.00	6.08	+0.08	+1.39%	[-0.34, +0.51]	12	0.674	1.000	not significant (increase)
202	4500-5400	HGV mean travel time (s)	578.26	582.70	+4.44	+0.77%	[+0.84, +8.03]	12	0.020	0.021	statistically significant, below practical threshold (unfavorable)
202	1800-5400 hour	HGV count	24.00	24.33	+0.33	+1.39%	[-0.16, +0.83]	12	0.166	0.312	negligible (not significant; 95% CI inside practical threshold)
202	1800-5400 hour	HGV mean travel time (s)	579.39	580.15	+0.77	+0.13%	[-0.74, +2.27]	12	0.287	0.301	negligible (not significant; 95% CI inside practical threshold)

Pairs < 12 indicate seeds with no HGV observation in that interval in at least one scenario. 15-minute means on Sections 101 and 202 rest on few trucks per seed and are noisy. "No net change" marks a count whose mean paired difference is exactly zero (the source file attaches a direction label to such rows).

Source: `S1_vs_S2_HIGH_HGV_TRAVEL_TIME.csv`.

R.D HGV Reliability Metrics

S2_LOW vs S1 – S1 → S2_LOW [bootstrap 95% CI of the difference]; pooled n = S1 / S2_LOW

Table 96. Toll-Bound Pricing: HGV Reliability Metrics, S2_LOW vs. S1

Section	Interval (s)	Rule allows	Pooled n	Mean (s)	SD (s)	P95 (s)	Buffer index	Planning time index
101	1800-2700	NO	49 / 49	603.4 → 605.0 [-1.0, +4.1]	26.0 → 25.3 [-2.6, +1.3]	not supported	not supported	not supported
101	2700-3600	NO	41 / 40	619.8 → 616.0 [-9.2, +1.7]	22.6 → 22.6 [-7.1, +6.5]	not supported	not supported	not supported
101	3600-4500	NO	61 / 62	635.7 → 630.0 [-9.8, -1.9]	24.6 → 24.6 [-6.6, +5.8]	not supported	not supported	not supported
101	4500-5400	NO	64 / 64	623.4 → 624.3 [-2.4, +4.1]	25.9 → 26.2 [-3.4, +4.4]	not supported	not supported	not supported
101	1800-5400 hour	YES	215 / 215	621.6 → 620.0 [-3.1, -0.1]	27.3 → 26.4 [-3.3, +1.3]	670.1 → 665.3 [-13.3, +8.8]	0.078 → 0.073 [-0.019, +0.016]	1.226 → 1.217 [-0.024, +0.016]
102	1800-2700	YES	160 / 161	539.1 → 540.2 [-1.1, +3.1]	18.4 → 19.0 [-2.3, +3.0]	571.5 → 574.6 [-3.2, +12.9]	0.060 → 0.064 [-0.006, +0.019]	1.165 → 1.171 [-0.006, +0.026]
102	2700-3600	YES	193 / 194	551.4 → 553.1 [-1.4, +5.0]	19.9 → 19.9 [-2.4, +2.7]	584.5 → 585.1 [-9.4, +12.1]	0.060 → 0.058 [-0.017, +0.016]	1.201 → 1.202 [-0.019, +0.025]
102	3600-4500	YES	208 / 206	587.5 → 591.5 [-1.5, +9.0]	28.9 → 27.8 [-4.8, +1.7]	636.4 → 645.1 [-8.4, +12.5]	0.083 → 0.090 [-0.018, +0.015]	1.304 → 1.321 [-0.017, +0.026]
102	4500-5400	YES	198 / 198	613.5 → 619.1 [-6.1, +19.3]	37.9 → 36.7 [-9.5, +5.4]	677.2 → 680.6 [-10.4, +16.0]	0.104 → 0.099 [-0.036, +0.018]	1.384 → 1.391 [-0.021, +0.033]
102	1800-5400 hour	YES	759 / 759	574.9 → 578.0 [-0.8, +7.9]	40.2 → 41.1 [-2.3, +4.2]	648.7 → 657.7 [-5.3, +19.6]	0.128 → 0.138 [-0.013, +0.022]	1.326 → 1.345 [-0.011, +0.040]
201	1800-2700	YES	268 / 265	494.5 → 493.6 [-2.3, +0.3]	16.3 → 15.8 [-1.5, +0.6]	522.2 → 522.2 [-3.7, +3.9]	0.056 → 0.058 [-0.005, +0.009]	1.127 → 1.127 [-0.008, +0.008]

Table 96. Toll-Bound Pricing: HGV Reliability Metrics, S2_LOW vs. S1 (continued)

Section	Interval (s)	Rule allows	Pooled n	Mean (s)	SD (s)	P95 (s)	Buffer index	Planning time index
201	2700-3600	YES	316 / 322	500.5 → 499.9 [-2.1, +0.9]	15.3 → 16.4 [-0.1, +2.1]	526.0 → 530.6 [-3.1, +8.3]	0.051 → 0.061 [-0.004, +0.017]	1.128 → 1.138 [-0.007, +0.018]
201	3600-4500	YES	331 / 327	505.7 → 504.0 [-3.6, +0.03]	16.0 → 16.0 [-1.8, +1.6]	536.0 → 531.8 [-10.0, +2.7]	0.060 → 0.055 [-0.014, +0.006]	1.149 → 1.140 [-0.021, +0.006]
201	4500-5400	YES	322 / 323	500.2 → 498.5 [-3.1, -0.4]	15.8 → 15.1 [-1.5, +0.3]	528.1 → 524.4 [-8.3, -0.4]	0.056 → 0.052 [-0.013, +0.003]	1.141 → 1.133 [-0.018, -0.001]
201	1800-5400 hour	YES	1237 / 1237	500.5 → 499.2 [-2.0, -0.6]	16.3 → 16.2 [-0.5, +0.4]	529.6 → 528.1 [-4.0, +1.2]	0.058 → 0.058 [-0.005, +0.005]	1.139 → 1.136 [-0.009, +0.003]
202	1800-2700	NO	59 / 61	573.7 → 570.7 [-5.4, -0.7]	19.6 → 20.1 [-1.4, +2.6]	not supported	not supported	not supported
202	2700-3600	NO	81 / 81	578.3 → 576.5 [-6.1, +2.2]	17.7 → 18.0 [-1.8, +3.1]	not supported	not supported	not supported
202	3600-4500	NO	76 / 77	585.9 → 583.3 [-6.2, -0.02]	19.6 → 19.9 [-1.9, +3.0]	not supported	not supported	not supported
202	4500-5400	NO	72 / 70	577.1 → 578.4 [-2.5, +4.7]	18.1 → 17.3 [-3.2, +2.8]	not supported	not supported	not supported
202	1800-5400 hour	YES	288 / 289	579.1 → 577.5 [-3.8, +0.5]	19.1 → 19.2 [-0.9, +1.1]	612.7 → 613.6 [-3.9, +5.1]	0.058 → 0.062 [-0.001, +0.010]	1.115 → 1.117 [-0.007, +0.009]

Source: `S1_vs_S2_LOW_HGV_RELIABILITY.csv`.

S2_HIGH vs S1 – S1 → S2_HIGH [bootstrap 95% CI of the difference]; pooled n = S1 / S2_HIGH

Table 97. Toll-Bound Pricing: HGV Reliability Metrics, S2_HIGH vs. S1

Section	Interval (s)	Rule allows	Pooled n	Mean (s)	SD (s)	P95 (s)	Buffer index	Planning time index
101	1800-2700	NO	49 / 50	603.4 → 604.5 [-2.5, +5.1]	26.0 → 24.4 [-4.3, +1.0]	not supported	not supported	not supported
101	2700-3600	NO	41 / 38	619.8 → 618.8 [-6.2, +4.8]	22.6 → 23.7 [-2.9, +3.7]	not supported	not supported	not supported
101	3600-4500	NO	61 / 63	635.7 → 633.2 [-6.9, +2.2]	24.6 → 23.7 [-7.2, +4.4]	not supported	not supported	not supported
101	4500-5400	NO	64 / 64	623.4 → 624.9 [-2.7, +4.2]	25.9 → 25.9 [-3.4, +2.7]	not supported	not supported	not supported

Table 97. Toll-Bound Pricing: HGV Reliability Metrics, S2_HIGH vs. S1 (continued)

Section	Interval (s)	Rule allows	Pooled n	Mean (s)	SD (s)	P95 (s)	Buffer index	Planning time index
101	1800-5400 hour	YES	215 / 215	621.6 → 621.5 [-1.8, +1.7]	27.3 → 26.6 [-2.3, +0.3]	670.1 → 665.6 [-8.6, +8.2]	0.078 → 0.071 [-0.014, +0.013]	1.226 → 1.217 [-0.016, +0.015]
102	1800-2700	YES	160 / 161	539.1 → 541.0 [-1.0, +4.2]	18.4 → 18.5 [-2.4, +2.0]	571.5 → 573.6 [-3.7, +10.6]	0.060 → 0.060 [-0.008, +0.014]	1.165 → 1.169 [-0.007, +0.022]
102	2700-3600	YES	193 / 193	551.4 → 552.9 [-0.9, +4.0]	19.9 → 20.5 [-1.5, +2.2]	584.5 → 586.0 [-8.8, +6.5]	0.060 → 0.060 [-0.016, +0.008]	1.201 → 1.204 [-0.018, +0.013]
102	3600-4500	YES	208 / 201	587.5 → 593.3 [-0.3, +11.8]	28.9 → 28.8 [-4.1, +2.9]	636.4 → 642.9 [-9.3, +15.6]	0.083 → 0.084 [-0.019, +0.011]	1.304 → 1.317 [-0.019, +0.032]
102	4500-5400	YES	198 / 197	613.5 → 624.7 [+2.0, +20.7]	37.9 → 36.2 [-8.6, +4.9]	677.2 → 686.2 [-7.3, +22.0]	0.104 → 0.098 [-0.035, +0.019]	1.384 → 1.403 [-0.015, +0.045]
102	1800-5400 hour	YES	759 / 752	574.9 → 579.9 [+0.9, +9.3]	40.2 → 42.8 [-0.3, +5.1]	648.7 → 656.2 [-7.2, +18.5]	0.128 → 0.132 [-0.019, +0.020]	1.326 → 1.342 [-0.015, +0.038]
201	1800-2700	YES	268 / 268	494.5 → 495.9 [+0.03, +3.0]	16.3 → 16.5 [-0.3, +0.7]	522.2 → 526.7 [+1.4, +10.2]	0.056 → 0.062 [-0.0003, +0.017]	1.127 → 1.137 [+0.003, +0.022]
201	2700-3600	YES	316 / 318	500.5 → 502.8 [+1.0, +3.7]	15.3 → 15.8 [-1.0, +1.9]	526.0 → 531.3 [+1.0, +8.9]	0.051 → 0.057 [-0.002, +0.013]	1.128 → 1.140 [+0.002, +0.019]
201	3600-4500	YES	331 / 327	505.7 → 507.3 [-1.1, +4.7]	16.0 → 16.4 [-1.5, +2.3]	536.0 → 539.7 [-5.4, +10.9]	0.060 → 0.064 [-0.010, +0.014]	1.149 → 1.157 [-0.012, +0.023]
201	4500-5400	YES	322 / 324	500.2 → 501.7 [-0.003, +3.0]	15.8 → 15.1 [-2.0, +0.8]	528.1 → 528.1 [-7.1, +4.6]	0.056 → 0.053 [-0.017, +0.004]	1.141 → 1.141 [-0.015, +0.010]
201	1800-5400 hour	YES	1237 / 1237	500.5 → 502.2 [+0.9, +2.5]	16.3 → 16.4 [-0.7, +1.0]	529.6 → 532.3 [-1.3, +6.1]	0.058 → 0.060 [-0.005, +0.008]	1.139 → 1.145 [-0.003, +0.013]
202	1800-2700	NO	59 / 63	573.7 → 570.9 [-5.5, -0.2]	19.6 → 20.2 [-0.9, +2.3]	not supported	not supported	not supported
202	2700-3600	NO	81 / 79	578.3 → 579.0 [-3.6, +5.2]	17.7 → 18.3 [-0.9, +3.5]	not supported	not supported	not supported
202	3600-4500	NO	76 / 77	585.9 → 587.2 [-0.9, +3.3]	19.6 → 19.4 [-3.4, +2.3]	not supported	not supported	not supported

Table 97. Toll-Bound Pricing: HGV Reliability Metrics, S2_HIGH vs. S1 (continued)

Section	Interval (s)	Rule allows	Pooled n	Mean (s)	SD (s)	P95 (s)	Buffer index	Planning time index
202	4500-5400	NO	72 / 73	577.1 → 581.2 [+1.2, +7.3]	18.1 → 19.2 [-1.5, +3.1]	not supported	not supported	not supported
202	1800-5400 hour	YES	288 / 292	579.1 → 580.0 [-0.4, +2.2]	19.1 → 19.9 [-0.3, +1.9]	612.7 → 617.0 [-2.2, +9.8]	0.058 → 0.064 [-0.004, +0.014]	1.115 → 1.123 [-0.004, +0.018]

Source: `S1_vs_S2_HIGH_HGV_RELIABILITY.csv`.

R.E Price Response by Managed-Lane Decision (Facility)

Table 98. Toll-Bound Pricing: Price Response by Toll Decision Point (Facility)

Facility	Dir.	Toll in force ($) LOW / S1 / HIGH	EL share (%) LOW / S1 / HIGH	p share LOW	p share HIGH	Transactions (veh) LOW / S1 / HIGH	Route completions (veh) LOW / S1 / HIGH	Share elasticity LOW / HIGH	Notes
51	EB	1.76 / 2.31 / 3.35	0.0 / 0.0 / 0.0	–	–	0.0 / 0.0 / 0.0	312.2 / 320.5 / 333.5	– / –	no managed-route demand in any seed
52	EB	0.96 / 1.16 / 1.60	20.9 / 19.2 / 15.4	<0.001	<0.001	285.5 / 261.2 / 211.3	1,160.8 / 1,163.1 / 1,158.0	-0.47 / -0.67	interior S1 share and toll change: preferred price-response indicator
53	EB	0.25 / 0.25 / 0.25	29.0 / 29.1 / 29.0	0.215	0.443	83.0 / 83.2 / 82.9	267.5 / 267.6 / 267.7	– / –	toll unchanged (both scenarios at the $0.25 floor)
54	EB	1.76 / 2.31 / 3.35	0.0 / 0.0 / 0.0	–	–	0.0 / 0.0 / 0.0	72.2 / 74.1 / 77.5	– / –	no managed-route demand in any seed
55	EB	0.96 / 1.16 / 1.60	22.1 / 20.0 / 16.0	<0.001	<0.001	137.1 / 123.8 / 99.9	540.4 / 541.1 / 539.5	-0.55 / -0.69	interior S1 share and toll change: preferred price-response indicator
56	EB	0.25 / 0.25 / 0.25	29.5 / 29.5 / 29.6	0.866	0.471	57.4 / 57.5 / 57.4	186.6 / 186.5 / 186.6	– / –	toll unchanged (both scenarios at the $0.25 floor)
57 (SR 417 to Dirksen)*	EB	1.26 / 1.81 / 2.70	12.8 / 9.6 / 6.0	<0.001	<0.001	146.2 / 111.9 / 70.2	1,052.0 / 1,063.5 / 1,072.8	-0.80 / -1.16	interior S1 share and toll change: preferred price-response indicator

Table 98. Toll-Bound Pricing: Price Response by Toll Decision Point (Facility) (continued)

Facility	Dir.	Toll in force ($) LOW / S1 / HIGH	EL share (%) LOW / S1 / HIGH	p share LOW	p share HIGH	Transactions (veh) LOW / S1 / HIGH	Route completions (veh) LOW / S1 / HIGH	Share elasticity LOW / HIGH	Notes
58 (SR 417 to OCR)*	EB	0.46 / 0.66 / 0.95	29.3 / 26.5 / 23.5	<0.001	<0.001	131.2 / 119.0 / 105.9	365.4 / 365.2 / 364.6	-0.29 / -0.32	interior S1 share and toll change: preferred price-response indicator
71	WB	1.35 / 1.85 / 2.80	18.8 / 15.0 / 9.0	<0.001	<0.001	191.4 / 152.7 / 91.8	809.3 / 807.7 / 805.8	-0.72 / -1.22	interior S1 share and toll change: preferred price-response indicator
72	WB	2.36 / 3.21 / 4.85	0.0 / 0.0 / 0.0	–	–	0.0 / 0.0 / 0.0	410.7 / 423.9 / 449.1	– / –	no managed-route demand in any seed
73	WB	1.60 / 2.15 / 3.25	100.0 / 100.0 / 100.0	–	–	204.5 / 153.8 / 84.0	164.8 / 124.2 / 68.2	– / –	GP-route completions never recorded (decision-73 travel-time notices); share reads 100%
74	WB	1.35 / 1.85 / 2.80	19.2 / 15.4 / 9.7	<0.001	<0.001	74.8 / 61.3 / 38.7	293.5 / 291.8 / 284.6	-0.70 / -1.11	interior S1 share and toll change: preferred price-response indicator
75	WB	1.56 / 2.11 / 3.20	0.0 / 0.0 / 0.0	–	–	0.0 / 0.0 / 0.0	589.8 / 602.6 / 628.1	– / –	no managed-route demand in any seed
76	WB	0.80 / 1.05 / 1.60	14.1 / 13.7 / 11.7	0.017	<0.001	281.1 / 289.8 / 273.0	1,517.2 / 1,558.5 / 1,612.7	-0.12 / -0.37	interior S1 share and toll change: preferred price-response indicator

Table 98. Toll-Bound Pricing: Price Response by Toll Decision Point (Facility) (continued)

Facility	Dir.	Toll in force ($) LOW / S1 / HIGH	EL share (%) LOW / S1 / HIGH	p share LOW	p share HIGH	Transactions (veh) LOW / S1 / HIGH	Route completions (veh) LOW / S1 / HIGH	Share elasticity LOW / HIGH	Notes
77	WB	0.55 / 0.75 / 1.15	17.8 / 16.6 / 15.8	0.020	0.005	318.3 / 340.5 / 375.5	483.3 / 495.1 / 509.8	-0.23 / -0.11	interior S1 share and toll change: preferred price-response indicator
78	WB	0.46 / 0.66 / 1.00	25.3 / 23.3 / 19.8	<0.001	<0.001	1,531.1 / 1,405.8 / 1,200.5	5,621.7 / 5,622.6 / 5,617.4	-0.24 / -0.39	interior S1 share and toll change: preferred price-response indicator

0–4,500 s, 12-seed means. Toll in force = mean of the six toll updates. Share elasticity = midpoint arc elasticity of the EL share at the decision with respect to the toll in force (decision-level price sensitivity). \ Facilities 57 and 58 are labelled by actual route geometry (Facility 57 is configured as "417 to OCR" and charged Segments 3+4; Facility 58 is configured as "417 to Dirksen" and charged Segment 3).*

Source: `S2_LOW_PRICE_RESPONSE_BY_FACILITY.csv`; `S2_HIGH_PRICE_RESPONSE_BY_FACILITY.csv`.

Total and price-responsive Express Lane traffic by segment (1,800–4,500 s)

Table 99. Toll-Bound Pricing: Total and Price-Responsive Express Lane Traffic by Segment (1,800-4,500 s)

Segment	Location	Measure	S2_LOW	S1	S2_HIGH	LOW vs S1	HIGH vs S1
1	EB Lake Mary - 417 Eg	A (veh)	1,357.5	1,332.2	1,284.9	+1.90%*	-3.55%*
1	EB Lake Mary - 417 Eg	B (veh)	385.2	359.4	313.0	+7.16%*	-12.91%*
1	EB Lake Mary - 417 Eg	B/A (%)	28.4	27.0	24.3	+5.17%*	-9.72%*
2	EB 417 Eg - 417 In	A (veh)	931.7	906.8	859.8	+2.74%*	-5.19%*
2	EB 417 Eg - 417 In	B (veh)	291.2	265.1	219.1	+9.84%*	-17.35%*
2	EB 417 Eg - 417 In	B/A (%)	31.2	29.2	25.5	+6.91%*	-12.83%*
3	EB 417 In - Dirksen	A (veh)	1,117.8	1,061.8	979.5	+5.27%*	-7.75%*
3	EB 417 In - Dirksen	B (veh)	481.3	425.8	343.9	+13.03%*	-19.24%*
3	EB 417 In - Dirksen	B/A (%)	43.1	40.1	35.1	+7.38%*	-12.44%*
4	EB Dirksen - OCR	A (veh)	447.4	440.4	432.0	+1.59%*	-1.91%*
4	EB Dirksen - OCR	B (veh)	91.7	84.2	75.1	+8.91%*	-10.79%*

Table 99. Toll-Bound Pricing: Total and Price-Responsive Express Lane Traffic by Segment (1,800-4,500 s) (continued)

Segment	Location	Measure	S2_LOW	S1	S2_HIGH	LOW vs S1	HIGH vs S1
4	EB Dirksen - OCR	B/A (%)	20.5	19.1	17.4	+7.24%*	-9.00%*
5	WB OCR - Dirksen	A (veh)	467.3	398.8	299.4	+17.20%*	-24.91%*
5	WB OCR - Dirksen	B (veh)	322.7	254.8	150.3	+26.66%*	-40.99%*
5	WB OCR - Dirksen	B/A (%)	69.1	63.9	50.3	+8.04%*	-21.34%*
6	WB Dirksen - 417	A (veh)	692.9	620.7	503.9	+11.64%*	-18.81%*
6	WB Dirksen - 417	B (veh)	747.7	703.6	613.8	+6.27%*	-12.77%*
6	WB Dirksen - 417	B/A (%)	107.9	113.4	121.9	-4.85%*	+7.45%*
7	WB 417 - 46A	A (veh)	449.5	414.3	353.2	+8.49%*	-14.76%*
7	WB 417 - 46A	B (veh)	335.2	307.8	251.3	+8.94%*	-18.33%*
7	WB 417 - 46A	B/A (%)	74.6	74.3	71.2	+0.38%	-4.16%*
8	WB 46A - Lake Mary	A (veh)	148.9	148.0	148.2	+0.62%	+0.17%
8	WB 46A - Lake Mary	B (veh)	0.0	0.0	0.0	–	–
8	WB 46A - Lake Mary	B/A (%)	0.0	0.0	0.0	–	–
9	WB Lake Mary - I-4	A (veh)	1,200.2	1,115.4	973.4	+7.60%*	-12.73%*
9	WB Lake Mary - I-4	B (veh)	1,064.6	979.2	837.8	+8.71%*	-14.44%*
9	WB Lake Mary - I-4	B/A (%)	88.7	87.8	86.1	+1.03%*	-1.95%*

A = all vehicles at the first EL detector station of the segment (priced and unpriced); B = toll transactions at decisions whose managed route uses the segment; B/A = price-responsive indicator (Section R.6). A vehicle can be counted at more than one decision, so B/A can exceed 100% (Segment 6). Segment 8 lies only on the managed routes of decisions 72 and 75, which carried no managed-route demand. = significant under the paired t-test and the exact Wilcoxon test ($p < 0.05$).*

Source: `S2_LOW_S1_S2_HIGH_FINAL_COMPARISON.csv`; `S1_PRICE_RESPONSIVE_EL_SUMMARY.csv`.

R.F Toll Behaviour by Segment

Table 100. Toll-Bound Pricing: Toll Behavior by Segment and Scenario

Seg.	Dir.	Scenario	LOS-A toll ($)	Mean toll ($)	SD ($)	Range ($)	Levels	% at LOS-A toll	LOS A / B / C+ updates	Toll changes	% clipped min	% clipped max	% at bound	% interior	Density mean / max (veh/mi/ln)
1	EB	S2_LOW	0.25	0.250	0.000	0.25 – 0.25	1	100.0	20 / 40 / 0	0	0.0	100.0	0.0	0.0	11.54 / 15.34
1	EB	S1	0.25	0.250	0.000	0.25 – 0.25	1	100.0	21 / 39 / 0	0	0.0	100.0	0.0	0.0	11.33 / 14.77
1	EB	S2_HIGH	0.25	0.250	0.000	0.25 – 0.25	1	100.0	23 / 37 / 0	0	0.0	98.3	0.0	1.7	10.88 / 14.48
2	EB	S2_LOW	0.25	0.250	0.000	0.25 – 0.25	1	100.0	59 / 1 / 0	0	0.0	100.0	0.0	0.0	7.66 / 11.14
2	EB	S1	0.25	0.250	0.000	0.25 – 0.25	1	100.0	60 / 0 / 0	0	1.7	98.3	0.0	0.0	7.45 / 10.42
2	EB	S2_HIGH	0.40	0.400	0.000	0.40 – 0.40	1	100.0	60 / 0 / 0	0	1.7	98.3	0.0	0.0	7.02 / 10.04
3	EB	S2_LOW	0.45	0.463	0.022	0.45 – 0.50	2	73.6	40 / 20 / 0	14	1.7	96.7	0.0	1.7	9.01 / 12.96
3	EB	S1	0.65	0.658	0.019	0.65 – 0.70	2	83.3	46 / 14 / 0	12	1.7	95.0	0.0	3.3	8.51 / 12.22
3	EB	S2_HIGH	0.95	0.952	0.010	0.95 – 1.00	2	95.8	57 / 3 / 0	4	0.0	100.0	0.0	0.0	7.77 / 11.28
4	EB	S2_LOW	0.80	0.800	0.000	0.80 – 0.80	1	100.0	60 / 0 / 0	0	1.7	98.3	0.0	0.0	3.34 / 5.32
4	EB	S1	1.15	1.150	0.000	1.15 – 1.15	1	100.0	60 / 0 / 0	0	0.0	100.0	0.0	0.0	3.27 / 5.23
4	EB	S2_HIGH	1.75	1.750	0.000	1.75 – 1.75	1	100.0	60 / 0 / 0	0	0.0	100.0	0.0	0.0	3.21 / 5.16
5	WB	S2_LOW	0.80	0.800	0.000	0.80 – 0.80	1	100.0	60 / 0 / 0	0	0.0	100.0	0.0	0.0	3.68 / 5.02
5	WB	S1	1.10	1.100	0.000	1.10 – 1.10	1	100.0	60 / 0 / 0	0	1.7	98.3	0.0	0.0	3.13 / 4.59
5	WB	S2_HIGH	1.65	1.650	0.000	1.65 – 1.65	1	100.0	60 / 0 / 0	0	0.0	100.0	0.0	0.0	2.34 / 3.48
6	WB	S2_LOW	0.55	0.550	0.000	0.55 – 0.55	1	100.0	60 / 0 / 0	0	0.0	100.0	0.0	0.0	5.26 / 7.55
6	WB	S1	0.75	0.750	0.000	0.75 – 0.75	1	100.0	60 / 0 / 0	0	0.0	100.0	0.0	0.0	4.71 / 6.86
6	WB	S2_HIGH	1.15	1.150	0.000	1.15 – 1.15	1	100.0	60 / 0 / 0	0	0.0	100.0	0.0	0.0	3.82 / 5.76
7	WB	S2_LOW	0.25	0.250	0.000	0.25 – 0.25	1	100.0	60 / 0 / 0	0	0.0	100.0	0.0	0.0	3.31 / 5.10
7	WB	S1	0.30	0.300	0.000	0.30 – 0.30	1	100.0	60 / 0 / 0	0	0.0	100.0	0.0	0.0	3.06 / 4.71
7	WB	S2_HIGH	0.45	0.450	0.000	0.45 – 0.45	1	100.0	60 / 0 / 0	0	0.0	25.0	75.0	0.0	2.60 / 4.34
8	WB	S2_LOW	0.30	0.300	0.000	0.30 – 0.30	1	100.0	60 / 0 / 0	0	0.0	100.0	0.0	0.0	1.09 / 1.86
8	WB	S1	0.40	0.400	0.000	0.40 – 0.40	1	100.0	60 / 0 / 0	0	0.0	100.0	0.0	0.0	1.09 / 1.86
8	WB	S2_HIGH	0.60	0.600	0.000	0.60 – 0.60	1	100.0	60 / 0 / 0	0	0.0	100.0	0.0	0.0	1.09 / 1.85
9	WB	S2_LOW	0.45	0.463	0.022	0.45 – 0.50	2	75.0	35 / 25 / 0	10	1.7	88.3	0.0	10.0	9.34 / 13.57
9	WB	S1	0.65	0.656	0.017	0.65 – 0.70	2	87.5	47 / 13 / 0	12	5.0	90.0	0.0	5.0	8.65 / 12.71
9	WB	S2_HIGH	1.00	1.001	0.006	1.00 – 1.05	2	98.6	59 / 1 / 0	2	1.7	98.3	0.0	0.0	7.51 / 11.13

Toll statistics over 12 seeds × 6 updates (72 values); LOS, changes and bound status over the 60 density-based updates (900–4,500 s). "At bound": the unconstrained toll equalled a LOS bound (at LOS A the minimum equals the maximum, so this includes tolls already at their pinned value).

Source: `S2_LOW_S1_S2_HIGH_TOLL_BEHAVIOUR_BY_SEGMENT.csv`.

R.G Source Files

All values in this report were read from the following approved Task 4.2 files in `Task4_Pricing\` (SHA-256 at report generation):

Table 101. Toll-Bound Pricing: Source Files of the Toll-Bound Analysis (SHA-256)

File	SHA-256 (first 16 hex)
S1_ANALYSIS_12RUN_FINAL_VALIDATION.txt	67C7A636D717678F
S1_TASK4_CONTROL_STATISTICS.csv	CA204002E905320E
S1_PRICE_RESPONSIVE_EL_SUMMARY.csv	BB151FF99F4494E0
S1_LOS_BOUND_ACTIVITY.csv	F6DC70D4BC9A6ED2
S1_DYNAMIC_TOLL_VARIABILITY_AUDIT.txt	401B41AC14E70824
S2_LOW_12RUN_FINAL_VALIDATION.txt	7DF5AC280267810B
S1_vs_S2_LOW_PAIRED_METRICS.csv	97F7D93728D1954C
S1_vs_S2_LOW_HGV_TRAVEL_TIME.csv	32AA89BCAF4D304E
S1_vs_S2_LOW_HGV_RELIABILITY.csv	F15FA18D6A238AD7
S1_vs_S2_LOW_EL_GP_OPERATIONAL_COMPARISON.csv	02335A950B6E2DC6
S2_LOW_PRICE_RESPONSE_BY_FACILITY.csv	CE915607F8A0EFC5
S2_HIGH_12RUN_FINAL_VALIDATION.txt	B9CBC4DB07DC6435
S1_vs_S2_HIGH_PAIRED_METRICS.csv	DD5CBB1E7BBCCC7E
S1_vs_S2_HIGH_HGV_TRAVEL_TIME.csv	09E93B765A0C995A
S1_vs_S2_HIGH_HGV_RELIABILITY.csv	D394A639AE0C5C01
S1_vs_S2_HIGH_EL_GP_OPERATIONAL_COMPARISON.csv	F6CDCE8669936BD2
S2_HIGH_PRICE_RESPONSE_BY_FACILITY.csv	B293B7364CCD42A9
S2_LOW_S1_S2_HIGH_FINAL_COMPARISON.csv	FEE37DBCC9DAA8DE
S2_LOW_S1_S2_HIGH_TASK42_SUMMARY_TABLE.csv	F070CD28BD63B97A
S2_LOW_S1_S2_HIGH_TOLL_BEHAVIOUR_BY_SEGMENT.csv	47DE3B36DA1A3717

Approved simulation packages (not modified): `S1_EXISTING_ANALYSIS_12Runs_Completed.zip` (SHA-256 1F18DCBF…AE2B), `S2_LOW_070_12Runs_Completed.zip` (5CF2E282…89DD), `S2_HIGH_150_Run12_Completed.zip` (5FC7B2EC…2202).

Report QC of the Toll-Bound Technical Report

```
S1 INCLUDED: YES
S2_LOW INCLUDED: YES
S2_HIGH INCLUDED: YES
12 PAIRED SEEDS USED: YES
EXTRA DUPLICATE S2_HIGH SEED-2222 EXCLUDED FROM STATISTICS: YES
REVENUE ANALYSIS INCLUDED: YES
PRICE ELASTICITY INCLUDED: YES
EL OPERATIONS INCLUDED: YES
GP OPERATIONS INCLUDED: YES
HGV TRAVEL TIME INCLUDED: YES
```

HGV RELIABILITY INCLUDED: YES
HGV EXCLUSION VALIDATED: YES
STATISTICAL VS PRACTICAL SIGNIFICANCE DISTINGUISHED: YES
LIMITATIONS INCLUDED: YES
TASK 4.3 TRANSITION INCLUDED: YES
READY FOR FDOT REPORT USE: YES

Appendix S. GP-Responsive Pricing Technical Analysis

About this appendix. This appendix reproduces the GP-responsive pricing sensitivity package, which supports Part V, Section 1.4: the GP-responsive report section (Sections S.1-S.9), its supporting technical detail (Sections S.A-S.L) and the final freeze note. Text, values and classifications are unchanged. For this report its headings, tables, figures and cross-references are renumbered, and the figure fonts are enlarged for print without changing the data. Three tables of the package are not repeated because Part V reports the same values: the scenario table (see Table 60), the sensitivity summary table (see Table 62) and the table of pricing sensitivities at baseline demand (see Table 61). Practical thresholds are those pre-established for this analysis (Section S.A) and are not harmonized with Subtask 4.2 retrospectively.

S.1 Motivation and Objective

The study model sets managed-lane tolls with a density-responsive controller that, every 15 minutes, converts the Express Lane (EL) density on each of nine toll segments into a level of service (LOS) and prices each segment within LOS-specific bounds. Under the 2040 PM conditions EL density stays low: in the existing-conditions scenario (S1) the controller never read worse than LOS B, and 96% of segment updates remained at the LOS-A toll. The controller therefore responds weakly even when General Purpose (GP) lane and freight conditions deteriorate.

The research team evaluated a GP-density-responsive pricing sensitivity, a controlled operational-strategy sensitivity in which the existing controller receives GP-lane density instead of EL density, to answer one question:

> *Would responding directly to GP congestion improve system performance, or would higher GP-triggered tolls discourage Express Lane use and leave additional vehicles in the congested GP lanes?*

The formulation was tested as a sensitivity only; it is not a tolling policy in use or under consideration.

S.2 Scenario Development and Experimental Design

The existing pricing mechanics were retained unchanged: LOS thresholds of 11, 18, 26, 35 and 45 veh/mi/lane, density-change adjustment from the delta table, LOS-specific bounds scaled by segment length, a $0.25 segment minimum and upward rounding to $0.05. The only controlled change was the input: GP density from 296 single-lane detectors on the I-4 mainline through lanes at the existing EL detector stations, so density stays in veh/mi/lane and no parameter needed conversion or recalibration.

Table 60 (Part V, Section 1.1) lists the scenarios used in the GP-responsive pricing sensitivity, their controller density input, demand, toll bounds and comparators.

Within each pair, demand, toll bounds, random seeds, vehicle compositions, routing and initial tolls are identical, so each comparison isolates one factor:

- **Density source:** GP_RESP vs S1 (baseline), GP_RESP_LOW vs S2_LOW (0.70x bounds), GP_RESP_D80 vs D80_ELController (80% demand) and GP_RESP_D120 vs D120 (120% demand).
- **Toll bounds under GP-responsive control:** GP_RESP_LOW vs GP_RESP.
- **Demand response:** GP_RESP_D80, GP_RESP and GP_RESP_D120, each read through its own comparator (an envelope, not a paired comparison).

All scenarios used the same 12 random seeds, paired by seed; tolls were updated every 900 s and traffic measured over the 1,800-5,400-s analysis hour. A change is statistically detectable when the paired t-test and exact Wilcoxon test both give $p < 0.05$; practical thresholds were 2% for travel time and 5% for network delay per vehicle and for pricing measures. Classification rules were fixed before the analysis (Section S.A).

S.3 Model and Controller Validation

- A control simulation with the 296 GP detectors installed but the existing controller active reproduced the approved S1 simulation exactly, confirming that the detectors measure traffic without affecting it.
- The GP-responsive controller used the validated pricing code unchanged, and every simulated toll was reproduced independently from the measured detector data.
- All 12 paired runs of each scenario were validated, and independent quality-control checks confirmed the reported results (Section S.K).

S.4 Baseline GP-Responsive Pricing Results

With GP density as input, the controller became far more active:

- GP density reached LOS C or D in 304 of 540 segment updates (56%), whereas the EL density read by S1 never exceeded LOS B.
- GP_RESP tolls were higher than S1 tolls in 400 of 540 (74%) segment updates and never lower.
- Segment 4 (EB Dirksen to OCR) reached its LOS-D ceiling of $4.30 in 10 of 12 seeds (S1 maximum: $1.15).
- The delta table altered the final toll in 36.5% of updates, against 3.1% under S1.

The stronger response changed toll magnitude, lane choice and revenue rather than corridor operations (Table 62):

- **Pricing and lane choice:** the average toll paid changed by +22.9%, toll transactions by -11.2%, the EL share by -11.4% and revenue by +9.1%.
- **Operations:** EB and WB GP travel time (+0.8% and +0.3%) and network delay per vehicle (+1.0%) changed by amounts that are statistically detectable but operationally small.

- **Freight:** the effect was localized. On Section 102 (EB US 17 to SR 472), HGV mean travel time rose 1.5% and the pooled 95th-percentile travel time 3.0%. Both direction totals stayed below 2% (EB +0.8%, WB +0.4%).

Under the pre-established rules, this small reliability deterioration classifies the baseline comparison as **not promising**.

S.5 Pricing-Bound Sensitivity

GP_RESP_LOW tested whether the baseline result was unfavorable mainly because the GP-triggered response was too aggressive. It applies the 0.70x bounds of the Task 4.2 reduced-bound case (S2_LOW) to the GP-density-responsive controller. Relative to GP_RESP, the lower bounds moderated pricing as intended. The average toll changed by -23.2%, the maximum segment toll fell from $4.30 to $3.00, transactions changed by +13.6% and revenue by -12.8%; operational changes were negligible.

The comparison with S2_LOW, which uses the same bounds with EL density, is the decisive one:

- GP_RESP_LOW raised the average toll by 23.3% and revenue by 14.2%, and changed transactions by -7.4%.
- It produced no measurable operational or freight benefit: EB and WB GP travel time +0.1% (n.s.) and +0.2%, network delay per vehicle +0.5%, and Section 102 HGV travel time +0.1% (n.s.).
- The localized Section 102 deterioration no longer appeared. Small detectable unfavorable differences remained, each below 0.5%: WB GP travel time, network delay per vehicle, and Section 201 HGV travel time.

Under the pre-established rule, the baseline weakness was therefore removed **partially**, and the comparison is **operationally neutral**.

> *Lowering the pricing bounds moderated the adverse baseline response but did not create an operational advantage. The GP-responsive LOW case functioned primarily as a higher-priced alternative to the conventional LOW case.*

S.6 Demand Sensitivity

Reduced Demand

At 80% demand the existing controller never priced above LOS A (0 of 540 segment updates). The GP-responsive controller did so in 328 of 540 segment updates (61%), as GP density reached LOS B-C. On a common GP-density measure the two arms had identical GP LOS distributions, never worse than LOS C (Section S.E). GP_RESP_D80 changed the average toll by +11.5%, revenue by +6.0% and transactions by -4.9%. GP travel time, network delay per vehicle and HGV travel time did not change by more than 0.2%. There was little congestion to manage: the controller stayed active but did not improve GP or freight performance. The comparison is **operationally neutral**.

Increased Demand

At 120% demand the GP-density input became substantially more aggressive:

- GP density reached LOS E or F in 44 of 540 segment updates (8%), while the existing controller read LOS C or worse in only 8 of 540 updates.
- The mean segment toll rose 177.4% and the average toll paid 42.0%.
- The highest tolls were $7.50 (Segment 3, 4,500-s update) for a segment and $15.40 (decision point 72, 4,500-s update) for a facility, against $1.15 and $3.25 under the existing controller (detail and pre-run indications: Section S.J).

The stronger response did not improve operations:

- **Lane choice:** transactions fell 26.5% and the EL share 23.8%. GP density on the common measure rose 7.3% (EB) and 4.6% (WB), and every GP section carried more traffic, so more vehicles remained in the GP lanes.
- **Operations:** WB GP travel time rose 3.8% and network delay per vehicle 6.8%, both above the practical thresholds. EB GP travel time (+1.3%) stayed below threshold.
- **Express Lanes:** the remaining Express Lane users gained slightly (EL travel time -1.4% EB, -0.7% WB).
- **Revenue:** revenue rose only 4.3%, below the 5% threshold.

Freight results differed by section. Section 102 HGV travel time fell 4.4%, while Section 101 immediately upstream rose 3.2% and Section 201 rose 7.2%. Under the pre-established section-level classification rules, the D120 comparison was classified as **mixed-tradeoff** because HGV effects differed by section. A supplementary corridor-level assessment nevertheless indicated no compensating freight benefit: westbound corridor HGV travel time increased approximately 3.6%, and eastbound changed by -0.3% (n.s.). The Section 102 gain therefore reflects delay redistributed within the eastbound direction, not a corridor benefit. The supplementary assessment supports the interpretation but does not replace the pre-established classification.

S.7 Operational, Freight, and Revenue Implications

Table 62 (Part V, Section 1.5) summarizes the four GP-responsive comparisons with the corresponding EL-density-responsive case: pricing, operational and freight responses and the pre-established classifications. Figures 109, 110 and 111 show the pricing, lane-choice and operational responses.

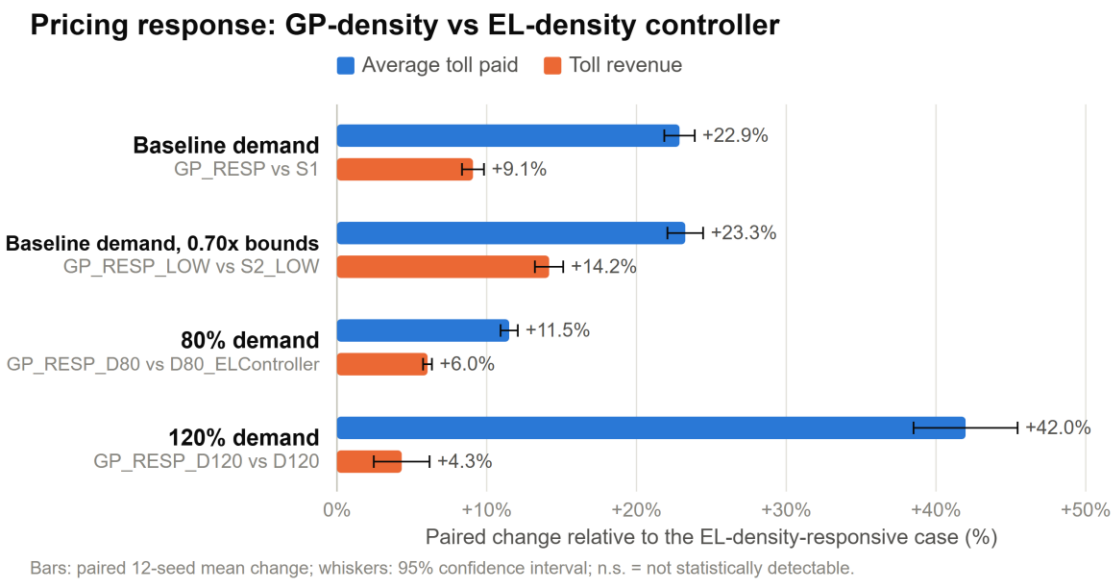

Figure 109. Pricing Response of the GP-Density-Responsive Controller

GP density as the controller input raised the average toll in every comparison (+11.5% to +42.0%); revenue rose less because fewer trips were sold.

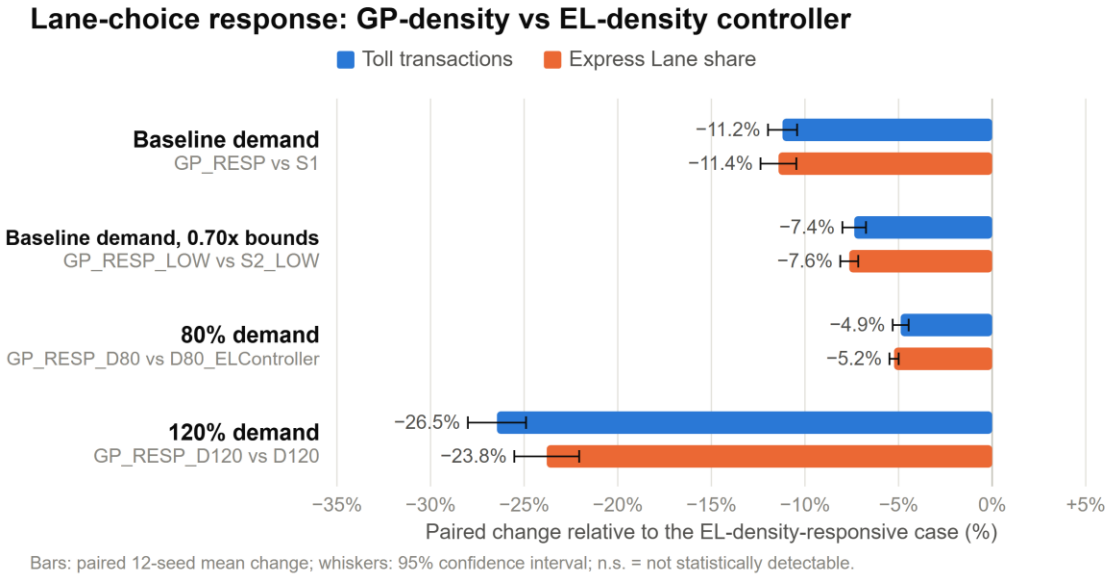

Figure 110. Lane-Choice Response of the GP-Density-Responsive Controller

Higher GP-triggered tolls reduced Express Lane use in every comparison, increasingly with demand (transactions -4.9%, -11.2% and -26.5% at 80%, 100% and 120% demand).

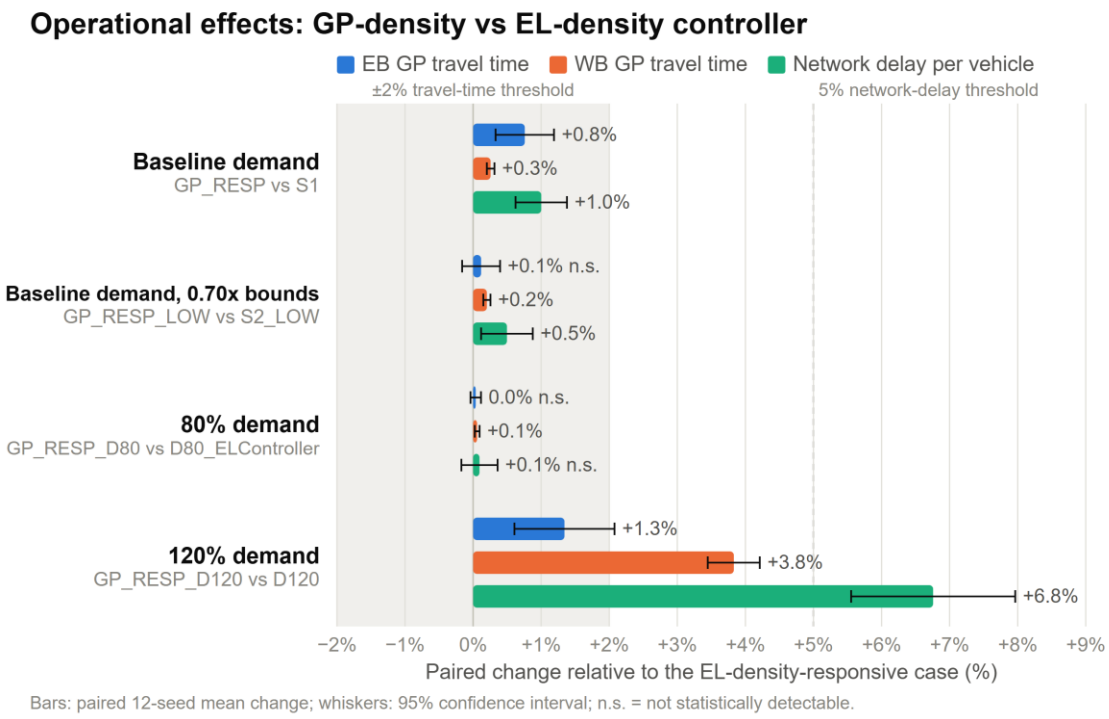

Figure 111. Operational Effects of the GP-Density-Responsive Controller

Operations were essentially unchanged with reduced bounds and at 80% demand (all within 0.5%) and changed by about 1% or less at baseline demand; at 120% demand WB GP travel time (+3.8%) and network delay per vehicle (+6.8%) exceeded the practical thresholds.

Demand response. GP-responsive pricing did not become more beneficial as congestion increased (Figure 112). At 80%, 100% and 120% demand, the GP-versus-EL effect on network delay per vehicle was +0.1% / +1.0% / +6.8%. On WB GP travel time it was +0.1% / +0.3% / +3.8%, on the EL share -5.2% / -11.4% / -23.8%, and on the average toll +11.5% / +22.9% / +42.0%. The pattern by demand level:

- low demand: operationally neutral;
- baseline demand: no operational benefit, with a weak adverse tendency;
- high demand: the strongest pricing response, with adverse GP and network effects.

Revenue gains (+6.0% / +9.1% / +4.3%) were largest at baseline demand and shrank at 120%, as transactions fell faster than tolls rose. They came from higher tolls on fewer trips, not from better service.

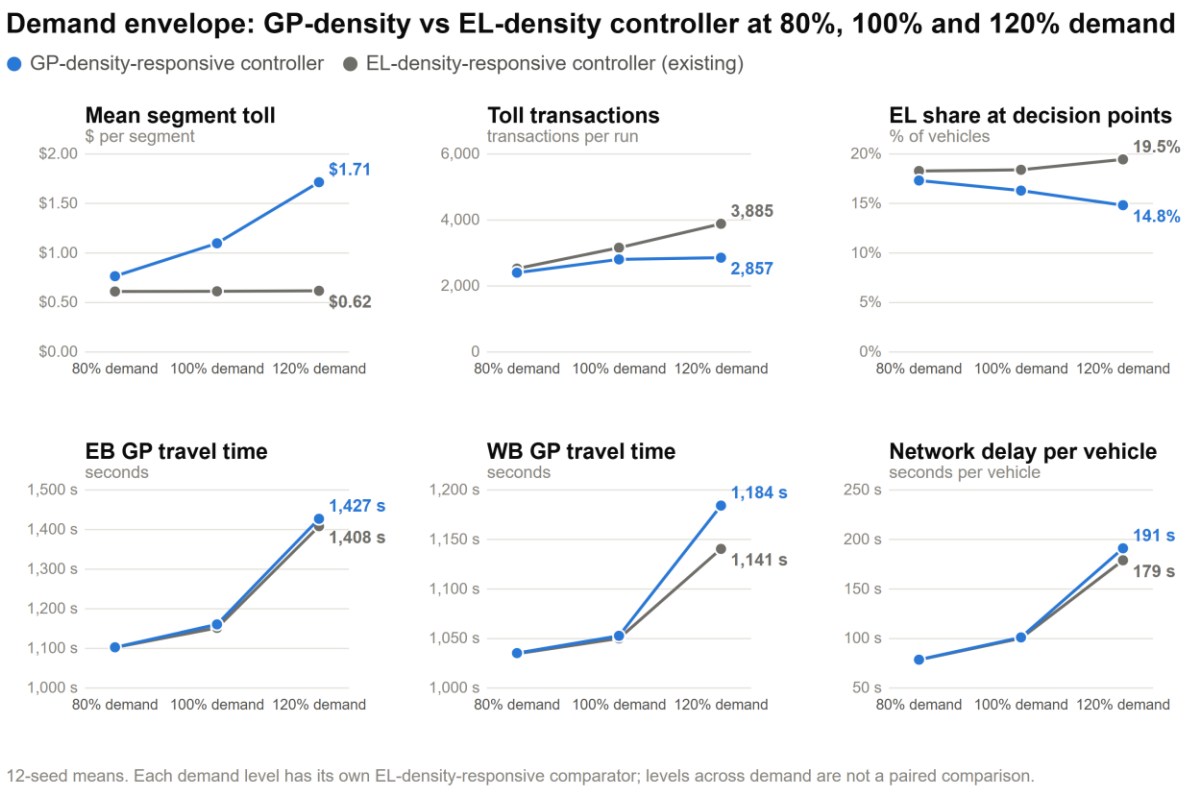

Figure 112. Demand Envelope of the GP-Density-Responsive Controller

As demand rises the GP-density-responsive controller charges progressively more and sells progressively fewer trips than the existing controller, while GP travel time and network delay are never lower (12-seed means; each demand level has its own comparator).

Controller activity. The lack of benefit was not caused by a controller that failed to respond (Table 102, Figure 113). With GP input, the delta table altered the final toll in 29.1-50.4% of updates, against 0.0-6.9% under the existing controller, and tolls rose through the peak, more steeply at higher demand. The controller responded strongly; that response did not produce the intended operational outcome.

Table 102. GP-Responsive Pricing: Controller Response by Scenario

Scenario	Controller density input	Demand	Toll bounds	Controller-input LOS C or worse (% of 540 segment updates)	GP LOS C or worse, common measure (% of 324 segment-intervals)	delta.csv altered final toll (% of 540 updates)	Mean segment toll	Maximum segment toll	Maximum facility toll
S1	EL density	100%	Standard	0.0%	76.5%	3.1%	$0.61	$1.15	$3.25
GP_RESP	GP density	100%	Standard	56.3%	76.5%	36.5%	$1.10	$4.30	$8.45
S2_LOW	EL density	100%	0.70x	0.0%	76.2%	4.1%	$0.46	$0.80	$2.40
GP_RESP_LOW	GP density	100%	0.70x	55.2%	76.2%	29.1%	$0.80	$3.00	$5.25
D80_ELController	EL density	80%	Standard	0.0%	53.4%	0.0%	$0.61	$1.15	$3.20
GP_RESP_D80	GP density	80%	Standard	33.3%	53.4%	33.9%	$0.77	$2.20	$4.80

Table 102. GP-Responsive Pricing: Controller Response by Scenario (continued)

Scenario	Controller density input	Demand	Toll bounds	Controller-input LOS C or worse (% of 540 segment updates)	GP LOS C or worse, common measure (% of 324 segment-intervals)	delta.csv altered final toll (% of 540 updates)	Mean segment toll	Maximum segment toll	Maximum facility toll
D120	EL density	120%	Standard	1.5%	77.8%	6.9%	$0.62	$1.15	$3.25
GP_RESP_D120	GP density	120%	Standard	66.3%	82.1%	50.4%	$1.71	$7.50	$15.40

Controller-input LOS: the density the controller read at its five density-based updates. Common measure: one GP-density method (link evaluation at the GP detector locations) applied to every scenario, 1,800-4,500 s. Maximum tolls: highest value in any seed and update.

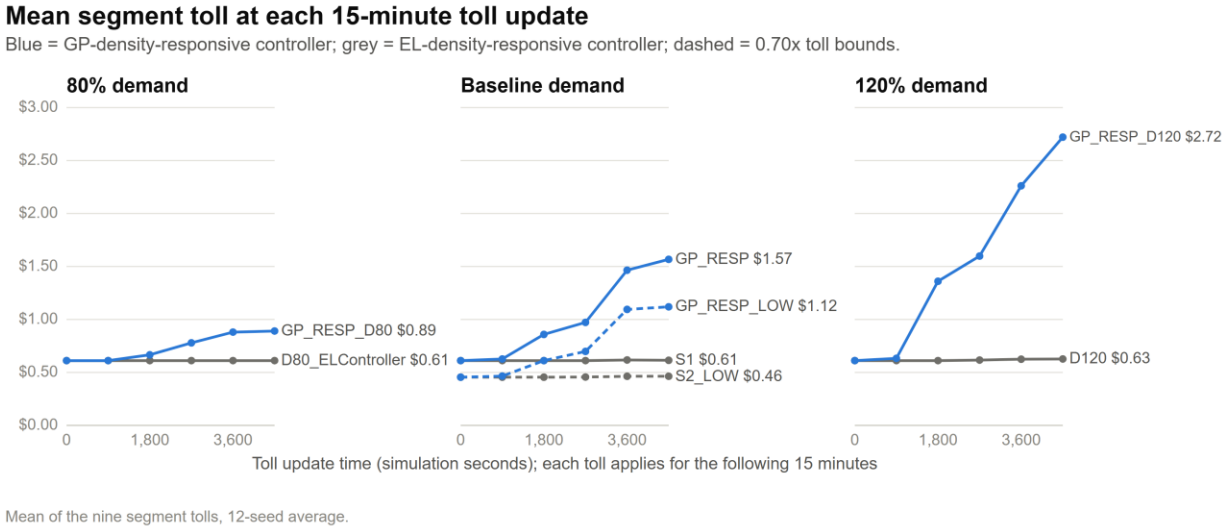

Figure 113. Mean Segment Toll at Each 15-Minute Update

Fed EL density, the existing controller holds tolls near their LOS-A values; fed GP density, the same logic raises tolls through the peak, more steeply as demand increases (mean segment toll $0.77, $1.10 and $1.71 against $0.61-$0.62).

Positive feedback. The concern was a loop in which GP congestion raises the GP-derived toll, the more expensive Express Lanes keep some single-occupant vehicles in the GP lanes, and GP congestion grows further.

- **Presence:** in all four comparisons the EL share fell and GP density rose, so the loop was present.
- **Strength:** it stayed below the pre-established criterion for moderate amplification. At 120% demand, GP LOS was worse than in the comparator in 28 and better in 3 of 324 segment-intervals (baseline: 19 and 0). The result is **weak amplifying feedback**.
- **Stability:** there was no toll oscillation, no throughput instability and no simulation instability.

The strategy is not unstable; its behavioral response works against the congestion-management objective.

Freight. No comparison showed a corridor-level freight benefit. HGV effects were negligible with reduced bounds and at 80% demand, localized to Section 102 at baseline demand, and mixed by section at 120% demand with a westbound corridor increase of 3.6% (Table 62; section and corridor detail in Section S.G and Figure 114).

Comparison with simpler pricing-bound changes. Under the tested conditions, GP-responsive pricing did not provide a clear operational advantage over the simpler pricing-bound changes evaluated in Task 4.2 (S2_LOW and S2_HIGH), which also changed prices and lane choice with operational effects within 1%. Additional comparison with the conventional pricing-bound sensitivity scenarios is provided in Section S.B and Table 61.

S.8 Discussion and Limitations

The controller responded as intended. Drivers' response to the higher tolls, however, was to leave the Express Lanes for the GP lanes, which worked against congestion management: it offset any benefit at low and baseline demand and outweighed it at 120% demand.

Classification. The four comparisons retain their pre-established classifications:

- baseline demand (GP_RESP vs S1): **not promising**;
- reduced bounds (GP_RESP_LOW vs S2_LOW) and reduced demand (GP_RESP_D80 vs D80_ELController): **operationally neutral**;
- increased demand (GP_RESP_D120 vs D120): **mixed-tradeoff**, with adverse GP and network operations and section-level freight results of opposite sign.

The overall finding is stated as **no demonstrated operational advantage** rather than as a single aggregated class. None of the four conditions produced an operational or corridor-level freight improvement over the corresponding EL-density-responsive case. Section S.A describes how this finding relates to the pre-established aggregation rule.

Limitations.

- The strategy reuses the existing EL-oriented LOS thresholds, delta table, pricing bounds, segment minimum and 15-minute update interval; none was re-derived for GP density.
- The GP-responsive controller was not independently optimized or calibrated as a deployable tolling policy.
- The analysis does not include agency-specific willingness-to-pay assumptions, revenue optimization, or policy constraints on toll levels.
- At 120% demand the 5,400-s horizon was only partially sufficient. GP density peaked in the final, unpriced 15 minutes in 45 of 108 seed-segments, which limits interpretation of the late period. The WB travel-time effect grew in every analysis interval (+0.1% / +1.6% / +3.8% / +8.1%) rather than reversing.

- The results represent the modeled I-4 study corridor and conditions. They should not be generalized to all GP-responsive tolling concepts; they show only that this tested formulation did not provide an operational advantage.

S.9 Conclusions and Recommendation

The GP-density-responsive pricing sensitivity was successfully implemented and produced a substantially stronger toll response than the existing EL-density-responsive controller. However, the additional responsiveness did not translate into a consistent operational advantage; its effects were on tolls, lane choice and revenue.

- **Reduced-bound, reduced-demand and baseline conditions:** operational effects were negligible, apart from a small localized freight-reliability effect at baseline.
- **Elevated demand:** the GP-responsive strategy reduced Express Lane utilization and was associated with increased GP travel time and network delay, and with a mixed freight response.
- **Pricing bounds:** reducing them moderated the response but did not provide an operational advantage over the comparable EL-density-responsive scenario.

Overall finding: no demonstrated operational advantage; no further testing of the current GP-responsive formulation is recommended.

Recommendation: STOP. Retain the results as Task 4.2 sensitivity evidence. Additional VISSIM simulation of the current formulation is not warranted, and no further development of this formulation is recommended within this study.

The analysis provides decision-support value by identifying a technically feasible strategy that does not warrant further development under the tested formulation, allowing subsequent modeling and implementation resources to be directed toward more promising operational strategies.

Supporting Technical Detail

Supporting material for Sections S.1-S.9: detail that is useful for technical review but not needed in the main report. All values come from the validated 12-seed analyses (baseline: `Task4_Pricing\GP_Responsive\Run12_Analysis\`; extensions: `Task4_Pricing\GP_Responsive\Screening_Extensions\Run12_Final_Analysis\`) and the Task 4.2 pricing analysis.

S.A Pre-established classification rules and the overall finding

The rules below were fixed before the results were analyzed (verbatim from the analysis record):

- Significance and practical thresholds as in the validated GP_RESP and Task 4.2/4.3 analyses: paired t-test and exact Wilcoxon both $p < 0.05$ ("sig2"); travel time / speed 2 %, volumes / pricing 5 %, delay 10 % (network delay per vehicle 5 %). The 3.3 % single-seed

bar for HGV section 102 of the screening design is reported as context only; 12-seed effects are judged with the established 2 % threshold and their confidence intervals.

- Operational effect (per GP-vs-EL comparison): indicators GP travel time EB/WB, EL travel time EB/WB, network delay per vehicle. WORSENS if >= 1 indicator has a sig2 unfavourable change >= its threshold and none a favourable one; IMPROVES symmetric; MIXED both; NEGLIGIBLE neither.
- Freight effect: WORSENS if >= 1 GP section 101/102/201/202 has a sig2 HGV hourly mean travel-time increase >= 2 % or a supported pooled hourly HGV P95/PTI increase >= 2 % with seed-pair bootstrap CI excluding 0, and no such improvement; IMPROVES symmetric; MIXED both; NEGLIGIBLE neither. Pooled statistics need n >= 30 (mean/SD) and n >= 100 (P95/BI/PTI); hourly for 101/202, hourly and 15-min for 102/201; 4,000 seed-pair bootstrap replicates.
- Revenue effect: INCREASES / DECREASES if total revenue changes with sig2 and |change| >= 5 %; else NEGLIGIBLE.
- Task 4.2 class per GP-vs-EL comparison: UNSTABLE-REQUIRES-REDESIGN if oscillation, throughput instability or MODERATE/STRONG AMPLIFYING feedback; PROMISING if operations or freight IMPROVES and neither WORSENS nor is MIXED; MIXED-TRADEOFF if one improves and the other worsens (or either is MIXED); NOT PROMISING if operations or freight WORSENS and nothing improves; OPERATIONALLY NEUTRAL if both NEGLIGIBLE.
- Overall: UNSTABLE-REQUIRES-REDESIGN if any condition is UNSTABLE; PROMISING if every condition is PROMISING; PROMISING ONLY UNDER SPECIFIC CONDITIONS if some are PROMISING; MIXED-TRADEOFF if any is MIXED-TRADEOFF; NOT PROMISING if any is NOT PROMISING; else OPERATIONALLY NEUTRAL. Conditions: baseline, LOW bounds, 80 % demand, 120 % demand.
- Next step: C (controller redesign required) if overall UNSTABLE; B (one targeted follow-up) if PROMISING ONLY UNDER SPECIFIC CONDITIONS or MIXED-TRADEOFF, or if the horizon is INSUFFICIENT for a scenario whose conclusion depends on it; D (additional matrix) only if the four comparisons disagree in a way no single follow-up can resolve; A (STOP) otherwise.

Supplementary corridor-level assessment (not part of the pre-established rules). After the rules had been applied, the HGV travel-time totals per direction (EB 101+102, WB 201+202) were examined to interpret the mixed section-level freight result at 120% demand. They are reported as supporting evidence only; Table 62 and Section S.6 keep the pre-established class (mixed-tradeoff) for that comparison.

Table 103. GP-Responsive Pricing: Comparison Classifications Under the Pre-Established Rules

Comparison	Operations	Freight (section level)	Revenue	Class (pre-established rules)	Corridor HGV EB / WB (supplementary)
GP_RESP vs S1	NEGLIGIBLE	WORSENS	INCREASES	**NOT PROMISING**	+0.8% / +0.4%
GP_RESP_LOW vs GP_RESP	NEGLIGIBLE	NEGLIGIBLE	DECREASES	**OPERATIONALLY NEUTRAL**	-0.6% / -0.4%
GP_RESP_LOW vs S2_LOW	NEGLIGIBLE	NEGLIGIBLE	INCREASES	**OPERATIONALLY NEUTRAL**	+0.1% / +0.2%
GP_RESP_D80 vs D80_ELController	NEGLIGIBLE	NEGLIGIBLE	INCREASES	**OPERATIONALLY NEUTRAL**	+0.1% / +0.2%
GP_RESP_D120 vs D120	WORSENS	MIXED	NEGLIGIBLE	**MIXED-TRADEOFF**	-0.3% / +3.6%

Overall finding. The report keeps the four individual classifications and states the overall finding as *no demonstrated operational advantage; no further testing of the current GP-responsive formulation is recommended*, rather than as a single aggregated class. Applied mechanically, the pre-established overall rule would return **MIXED-TRADEOFF**, because one condition (120% demand) carries that class, and the next-step rule would then indicate one targeted follow-up simulation. The final reporting decision does not adopt that follow-up:

- no condition produced an operational improvement;
- the only favorable element of the 120% result (Section 102) is explained by the corridor totals from the same runs;
- the analysis is frozen.

S.B Comparison with the conventional pricing-bound sensitivities

The pricing sensitivities at baseline demand relative to S1 (S2_LOW, S2_HIGH, GP_RESP and GP_RESP_LOW) are reported in Table 61 (Part V, Section 1.5), which adds the S1 reference values.

At baseline demand, raising the bounds of the existing controller by 50% (S2_HIGH) changed the average toll by +39.7%, transactions by -14.9%, the EL share by -18.3% and revenue by +18.9%, with GP travel time and network delay per vehicle within 1%. GP_RESP moved prices and lane choice in the same direction but by less, with similarly small operational effects. GP_RESP_LOW ended close to S1 in lane choice and operations (transactions +0.9%, network delay per vehicle +0.4% (n.s.)). Percentages are computed from full-precision values and rounded once (for example, S2_HIGH transactions -14.850% is reported as -14.9%).

S.C Paired statistics, key measures

Table 104. GP-Responsive Pricing: Paired Statistics for Key Measures

Comparison	Measure	Comparator mean	GP-responsive mean	% change	95% CI	Seeds up/down/unchanged	p (t)	p (Wilcoxon)	Detectable
GP_RESP vs S1	toll transactions	3,160.417	2,806.500	-11.20%	-11.97% to -10.42%	0/12/0	0.0000	0.0005	yes
GP_RESP vs S1	EL share	0.184	0.163	-11.42%	-12.37% to -10.46%	0/12/0	0.0000	0.0005	yes
GP_RESP vs S1	average toll paid	0.940	1.155	+22.87%	+21.85% to +23.89%	12/0/0	0.0000	0.0005	yes
GP_RESP vs S1	toll revenue	2,969.600	3,239.375	+9.08%	+8.35% to +9.82%	12/0/0	0.0000	0.0005	yes
GP_RESP vs S1	EB GP travel time	1,151.716	1,160.459	+0.76%	+0.33% to +1.19%	11/1/5	0.0025	0.0024	yes
GP_RESP vs S1	WB GP travel time	1,050.073	1,052.778	+0.26%	+0.20% to +0.31%	12/0/12	0.0000	0.0005	yes
GP_RESP vs S1	EB EL travel time	553.798	551.842	-0.35%	-0.44% to -0.27%	0/12/11	0.0000	0.0005	yes
GP_RESP vs S1	WB EL travel time	754.557	752.767	-0.24%	-0.34% to -0.14%	0/12/12	0.0003	0.0005	yes
GP_RESP vs S1	network delay per vehicle	100.146	101.148	+1.00%	+0.62% to +1.38%	12/0/2	0.0001	0.0005	yes
GP_RESP_LOW vs GP_RESP	toll transactions	2,806.500	3,188.000	+13.59%	+12.51% to +14.68%	12/0/0	0.0000	0.0005	yes
GP_RESP_LOW vs GP_RESP	EL share	0.163	0.189	+16.01%	+14.93% to +17.09%	12/0/0	0.0000	0.0005	yes
GP_RESP_LOW vs GP_RESP	average toll paid	1.155	0.887	-23.21%	-23.80% to -22.63%	0/12/0	0.0000	0.0005	yes
GP_RESP_LOW vs GP_RESP	toll revenue	3,239.375	2,825.846	-12.77%	-13.48% to -12.05%	0/12/0	0.0000	0.0005	yes
GP_RESP_LOW vs GP_RESP	EB GP travel time	1,160.459	1,154.906	-0.48%	-0.89% to -0.07%	3/9/5	0.0264	0.0342	yes
GP_RESP_LOW vs GP_RESP	WB GP travel time	1,052.778	1,051.021	-0.17%	-0.22% to -0.12%	0/12/12	0.0000	0.0005	yes
GP_RESP_LOW vs GP_RESP	EB EL travel time	551.842	553.047	+0.22%	+0.09% to +0.35%	10/2/11	0.0039	0.0024	yes
GP_RESP_LOW vs GP_RESP	WB EL travel time	752.767	753.705	+0.12%	+0.06% to +0.19%	11/1/12	0.0019	0.0024	yes
GP_RESP_LOW vs GP_RESP	network delay per vehicle	101.148	100.515	-0.63%	-1.04% to -0.22%	3/9/5	0.0063	0.0093	yes

Table 104. GP-Responsive Pricing: Paired Statistics for Key Measures (continued)

Comparison	Measure	Comparator mean	GP-responsive mean	% change	95% CI	Seeds up/down/unchanged	p (t)	p (Wilcoxon)	Detectable
GP_RESP_LOW vs S2_LOW	toll transactions	3,441.583	3,188.000	-7.37%	-8.00% to -6.74%	0/12/0	0.0000	0.0005	yes
GP_RESP_LOW vs S2_LOW	EL share	0.205	0.189	-7.63%	-8.11% to -7.15%	0/12/0	0.0000	0.0005	yes
GP_RESP_LOW vs S2_LOW	average toll paid	0.719	0.887	+23.26 %	+22.07 % to +24.45 %	12/0/0	0.0000	0.0005	yes
GP_RESP_LOW vs S2_LOW	toll revenue	2,475.258	2,825.846	+14.16 %	+13.22 % to +15.11 %	12/0/0	0.0000	0.0005	yes
GP_RESP_LOW vs S2_LOW	EB GP travel time	1,153.559	1,154.906	+0.12%	-0.16% to +0.40%	6/6/7	0.3760	0.5185	no
GP_RESP_LOW vs S2_LOW	WB GP travel time	1,048.897	1,051.021	+0.20%	+0.15% to +0.25%	12/0/12	0.0000	0.0005	yes
GP_RESP_LOW vs S2_LOW	EB EL travel time	554.809	553.047	-0.32%	-0.44% to -0.19%	1/11/10	0.0002	0.0010	yes
GP_RESP_LOW vs S2_LOW	WB EL travel time	755.493	753.705	-0.24%	-0.30% to -0.18%	0/12/12	0.0000	0.0005	yes
GP_RESP_LOW vs S2_LOW	network delay per vehicle	100.018	100.515	+0.50%	+0.12% to +0.88%	10/2/5	0.0148	0.0161	yes
GP_RESP_D80 vs D80_ELController	toll transactions	2,526.167	2,402.750	-4.89%	-5.31% to -4.46%	0/12/0	0.0000	0.0005	yes
GP_RESP_D80 vs D80_ELController	EL share	0.183	0.173	-5.24%	-5.49% to -4.99%	0/12/0	0.0000	0.0005	yes
GP_RESP_D80 vs D80_ELController	average toll paid	0.932	1.039	+11.50 %	+10.93 % to +12.08 %	12/0/0	0.0000	0.0005	yes
GP_RESP_D80 vs D80_ELController	toll revenue	2,353.746	2,496.067	+6.05%	+5.75% to +6.34%	12/0/0	0.0000	0.0005	yes
GP_RESP_D80 vs D80_ELController	EB GP travel time	1,102.440	1,102.868	+0.04%	-0.04% to +0.12%	7/5/12	0.2910	0.5185	no
GP_RESP_D80 vs D80_ELController	WB GP travel time	1,034.713	1,035.324	+0.06%	+0.02% to +0.09%	10/2/12	0.0039	0.0049	yes
GP_RESP_D80 vs D80_ELController	EB EL travel time	549.799	549.108	-0.13%	-0.20% to -0.05%	2/10/12	0.0038	0.0034	yes

Table 104. GP-Responsive Pricing: Paired Statistics for Key Measures (continued)

Comparison	Measure	Comparator mean	GP-responsive mean	% change	95% CI	Seeds up/down/unchanged	p (t)	p (Wilcoxon)	Detectable
GP_RESP_D80 vs D80_ELController	WB EL travel time	752.234	751.859	-0.05%	-0.09% to -0.01%	3/9/12	0.0295	0.0342	yes
GP_RESP_D80 vs D80_ELController	network delay per vehicle	78.508	78.582	+0.09%	-0.17% to +0.36%	7/5/11	0.4534	0.5185	no
GP_RESP_D120 vs D120	toll transactions	3,884.833	2,857.167	-26.45%	-28.00% to -24.90%	0/12/0	0.0000	0.0005	yes
GP_RESP_D120 vs D120	EL share	0.195	0.148	-23.80%	-25.53% to -22.06%	0/12/0	0.0000	0.0005	yes
GP_RESP_D120 vs D120	average toll paid	0.965	1.370	+41.98 %	+38.50 % to +45.45 %	12/0/0	0.0000	0.0005	yes
GP_RESP_D120 vs D120	toll revenue	3,748.137	3,910.171	+4.32%	+2.46% to +6.19%	12/0/1	0.0003	0.0005	yes
GP_RESP_D120 vs D120	EB GP travel time	1,408.485	1,427.385	+1.34%	+0.61% to +2.08%	10/2/3	0.0020	0.0034	yes
GP_RESP_D120 vs D120	WB GP travel time	1,140.536	1,184.206	+3.83%	+3.45% to +4.21%	12/0/0	0.0000	0.0005	yes
GP_RESP_D120 vs D120	EB EL travel time	562.438	554.748	-1.37%	-1.52% to -1.21%	0/12/0	0.0000	0.0005	yes
GP_RESP_D120 vs D120	WB EL travel time	757.002	751.563	-0.72%	-0.84% to -0.59%	0/12/2	0.0000	0.0005	yes
GP_RESP_D120 vs D120	network delay per vehicle	178.994	191.092	+6.76%	+5.55% to +7.96%	12/0/0	0.0000	0.0005	yes

Seed counts: up / down / essentially unchanged (|difference| <= 0.5% of the comparator). Detectable = paired t-test and exact Wilcoxon $p < 0.05$.

S.D Seed-level paired changes (%), selected measures

Table 105. GP-Responsive Pricing: Seed-Level Paired Changes for Selected Measures (%)

Comparison	Measure	2222	3333	4444	5555	6666	7777	8888	9999	11110	12221	13332	14443
GP_RESP vs S1	toll transactions	-11.5	-11.5	-11.4	-13.7	-9.9	-9.1	-11.6	-11.2	-12.8	-10.2	-10.6	-10.9
GP_RESP vs S1	WB GP travel time	+0.2	+0.3	+0.3	+0.5	+0.1	+0.2	+0.3	+0.2	+0.2	+0.2	+0.3	+0.3
GP_RESP vs S1	network delay per vehicle	+1.1	+0.6	+0.7	+0.8	+2.3	+1.2	+0.4	+1.1	+2.1	+0.6	+0.5	+0.8
GP_RESP vs S1	HGV mean travel time, Section 102	+1.6	+2.4	+1.5	+0.7	+2.7	+3.6	+0.3	-0.2	+3.9	+1.4	-1.9	+1.9
GP_RESP_LOW vs S2_LOW	toll transactions	-6.9	-8.1	-7.2	-6.6	-6.6	-8.1	-6.7	-8.7	-7.7	-6.7	-5.9	-9.0
GP_RESP_LOW vs S2_LOW	WB GP travel time	+0.2	+0.2	+0.2	+0.2	+0.2	+0.3	+0.4	+0.1	+0.1	+0.1	+0.2	+0.2

Table 105. GP-Responsive Pricing: Seed-Level Paired Changes for Selected Measures (%) (continued)

Comparison	Measure	2222	3333	4444	5555	6666	7777	8888	9999	11110	12221	13332	14443
GP_RESP_LOW vs S2_LOW	network delay per vehicle	+0.9	-0.2	+1.7	-0.6	+0.4	+0.9	+0.2	+0.1	+0.5	+0.7	+1.0	+0.4
GP_RESP_LOW vs S2_LOW	HGV mean travel time, Section 102	+0.2	-1.1	+1.6	-0.4	-0.2	+0.1	-0.5	+1.1	-1.5	-0.2	+0.3	+2.1
GP_RESP_D80 vs D80_ELController	toll transactions	-3.4	-5.4	-5.2	-4.8	-4.6	-6.0	-4.4	-5.1	-5.2	-4.9	-4.1	-5.5
GP_RESP_D80 vs D80_ELController	WB GP travel time	+0.0	+0.1	+0.1	+0.1	-0.0	-0.1	+0.1	+0.1	+0.1	+0.0	+0.1	+0.1
GP_RESP_D80 vs D80_ELController	network delay per vehicle	-0.3	-0.2	-0.2	+0.3	-0.3	+0.3	+1.0	+0.3	-0.5	+0.2	+0.4	+0.1
GP_RESP_D80 vs D80_ELController	HGV mean travel time, Section 102	+0.4	+0.1	-0.5	-0.1	+0.2	-0.0	-0.5	+1.2	-0.6	-0.1	+0.3	-0.1
GP_RESP_D120 vs D120	toll transactions	-26.4	-22.3	-28.3	-27.0	-28.0	-28.5	-22.7	-30.5	-26.8	-24.6	-25.4	-26.9
GP_RESP_D120 vs D120	WB GP travel time	+3.2	+4.6	+4.0	+4.3	+4.2	+4.3	+3.3	+3.4	+4.3	+2.5	+4.1	+3.7
GP_RESP_D120 vs D120	network delay per vehicle	+8.1	+3.5	+10.7	+7.6	+5.1	+5.2	+7.4	+5.6	+5.2	+6.4	+8.7	+7.8
GP_RESP_D120 vs D120	HGV mean travel time, Section 102	-3.8	-6.4	-3.4	+0.2	-4.7	-5.2	-5.8	-4.0	-8.7	-4.1	-3.0	-3.6

S.E LOS distributions

Table 106. GP-Responsive Pricing: Controller-Input and Common GP LOS Distributions

Scenario	Controller input	Controller-input LOS A/B/C/D/E/F (540 updates)	Common GP LOS A/B/C/D/E/F (324 segment-intervals)
S1	EL density	474 / 66 / 0 / 0 / 0 / 0	13 / 63 / 178 / 70 / 0 / 0
GP_RESP	GP density	95 / 141 / 213 / 91 / 0 / 0	12 / 64 / 160 / 88 / 0 / 0
S2_LOW	EL density	454 / 86 / 0 / 0 / 0 / 0	13 / 64 / 183 / 64 / 0 / 0
GP_RESP_LOW	GP density	96 / 146 / 219 / 79 / 0 / 0	13 / 64 / 172 / 75 / 0 / 0
D80_ELController	EL density	525 / 15 / 0 / 0 / 0 / 0	48 / 103 / 173 / 0 / 0 / 0
GP_RESP_D80	GP density	163 / 197 / 179 / 1 / 0 / 0	48 / 103 / 173 / 0 / 0 / 0
D120	EL density	412 / 120 / 8 / 0 / 0 / 0	0 / 72 / 48 / 163 / 17 / 24
GP_RESP_D120	GP density	72 / 110 / 117 / 197 / 30 / 14	0 / 58 / 62 / 160 / 12 / 32

At 80% demand the common GP LOS distribution was identical in both arms (LOS A 48, B 103, C 173 of 324 segment-intervals).

S.F Toll-band position, delta.csv activity and bound saturation (540 segment updates per scenario)

Table 107. GP-Responsive Pricing: Toll-Band Position, Density-Change Table Activity and Bound Saturation

Scenario	Single-value LOS-A toll	At LOS lower bound	Inside LOS band	At LOS upper bound	Above LOS-A level	delta.csv altered toll	Max delta effect	Altered updates by LOS
S1	474	1	5	60	21	17 (3.1%)	$0.05	B 17
GP_RESP	95	4	70	371	400	197 (36.5%)	$2.15	B 49, C 81, D 67
S2_LOW	454	1	7	78	37	22 (4.1%)	$0.05	B 22
GP_RESP_LOW	96	2	21	421	305	157 (29.1%)	$1.50	B 34, C 74, D 49
D80_ELController	525	0	0	15	0	0 (0.0%)	$0.00	-
GP_RESP_D80	163	6	64	307	328	183 (33.9%)	$0.50	B 83, C 99, D 1
D120	412	1	2	125	77	37 (6.9%)	$0.05	B 37
GP_RESP_D120	72	15	112	341	442	272 (50.4%)	$2.05	B 50, C 53, D 138, E 29, F 2

The GP-responsive tolls sit mostly at the upper bound of the prevailing LOS band, so the toll behaves largely as a step function of GP LOS. The share inside a band is largest at 120% demand, where GP density moves through the wide LOS D-F bands and the delta table is most active.

S.G HGV results by section and corridor direction

Table 108. GP-Responsive Pricing: HGV Results by Section and Corridor Direction

Comparison	Section	HGV mean TT change [95% CI]	Detectable	Pooled hourly P95 (s)	Pooled hourly PTI
GP_RESP vs S1	101	+0.21% [-0.19% to +0.61%]	no	670.1 -> 670.1 (0.0%; CI includes 0)	1.225 -> 1.225 (0.0%; CI includes 0)
GP_RESP vs S1	102	+1.47% [+0.45% to +2.49%]	yes	648.7 -> 667.9 (+3.0%; CI excludes 0)	1.326 -> 1.366 (+3.0%; CI excludes 0)
GP_RESP vs S1	201	+0.40% [+0.25% to +0.55%]	yes	529.6 -> 531.1 (+0.3%; CI includes 0)	1.139 -> 1.143 (+0.3%; CI includes 0)
GP_RESP vs S1	202	+0.38% [-0.04% to +0.80%]	no	612.7 -> 620.9 (+1.3%; CI excludes 0)	1.115 -> 1.130 (+1.3%; CI excludes 0)
GP_RESP_LOW vs S2_LOW	101	+0.08% [-0.20% to +0.37%]	no	665.3 -> 662.1 (-0.5%; CI includes 0)	1.217 -> 1.212 (-0.5%; CI includes 0)
GP_RESP_LOW vs S2_LOW	102	+0.13% [-0.55% to +0.80%]	no	657.7 -> 660.8 (+0.5%; CI includes 0)	1.345 -> 1.351 (+0.5%; CI includes 0)
GP_RESP_LOW vs S2_LOW	201	+0.36% [+0.13% to +0.59%]	yes	528.1 -> 531.3 (+0.6%; CI excludes 0)	1.136 -> 1.143 (+0.6%; CI excludes 0)

Table 108. GP-Responsive Pricing: HGV Results by Section and Corridor Direction (continued)

Comparison	Section	HGV mean TT change [95% CI]	Detectable	Pooled hourly P95 (s)	Pooled hourly PTI
GP_RESP_LOW vs S2_LOW	202	+0.07% [-0.14% to +0.29%]	no	613.6 -> 612.8 (-0.1%; CI includes 0)	1.116 -> 1.115 (-0.1%; CI includes 0)
GP_RESP_D80 vs D80_ELController	101	+0.09% [-0.14% to +0.32%]	no	648.6 -> 649.0 (+0.1%; CI includes 0)	1.188 -> 1.189 (+0.1%; CI includes 0)
GP_RESP_D80 vs D80_ELController	102	+0.03% [-0.28% to +0.34%]	no	576.7 -> 577.5 (+0.1%; CI includes 0)	1.179 -> 1.180 (+0.1%; CI includes 0)
GP_RESP_D80 vs D80_ELController	201	+0.14% [0.00% to +0.27%]	no	518.4 -> 519.3 (+0.2%; CI includes 0)	1.114 -> 1.116 (+0.2%; CI includes 0)
GP_RESP_D80 vs D80_ELController	202	+0.21% [-0.13% to +0.55%]	no	608.5 -> 606.9 (-0.3%; CI includes 0)	1.111 -> 1.108 (-0.3%; CI includes 0)
GP_RESP_D120 vs D120	101	+3.25% [+0.39% to +6.10%]	yes	1184.0 -> 1231.2 (+4.0%; CI excludes 0)	2.123 -> 2.208 (+4.0%; CI excludes 0)
GP_RESP_D120 vs D120	102	-4.42% [-5.88% to -2.95%]	yes	946.8 -> 857.9 (-9.4%; CI excludes 0)	1.935 -> 1.753 (-9.4%; CI excludes 0)
GP_RESP_D120 vs D120	201	+7.21% [+5.42% to +9.00%]	yes	692.3 -> 841.1 (+21.5%; CI excludes 0)	1.488 -> 1.807 (+21.5%; CI excludes 0)
GP_RESP_D120 vs D120	202	+0.42% [-1.51% to +2.35%]	no	843.2 -> 861.9 (+2.2%; CI includes 0)	1.553 -> 1.588 (+2.2%; CI includes 0)
GP_RESP vs S1	EB corridor	+0.82% [+0.27% to +1.36%]	yes		
GP_RESP vs S1	WB corridor	+0.39% [+0.18% to +0.59%]	yes		
GP_RESP_LOW vs S2_LOW	EB corridor	+0.11% [-0.30% to +0.51%]	no		
GP_RESP_LOW vs S2_LOW	WB corridor	+0.21% [+0.03% to +0.39%]	yes		
GP_RESP_D80 vs D80_ELController	EB corridor	+0.06% [-0.09% to +0.21%]	no		
GP_RESP_D80 vs D80_ELController	WB corridor	+0.17% [-0.04% to +0.38%]	no		

Table 108. GP-Responsive Pricing: HGV Results by Section and Corridor Direction (continued)

Comparison	Section	HGV mean TT change [95% CI]	Detectable	Pooled hourly P95 (s)	Pooled hourly PTI
GP_RESP_D120 vs D120	EB corridor	-0.34% [-2.07% to +1.38%]	no		
GP_RESP_D120 vs D120	WB corridor	+3.56% [+2.66% to +4.46%]	yes		

Pooled hourly HGV P95 and planning-time index (PTI) use all HGV trips of the 12 seeds (n >= 100 required) with a 4,000-replicate seed-pair bootstrap.

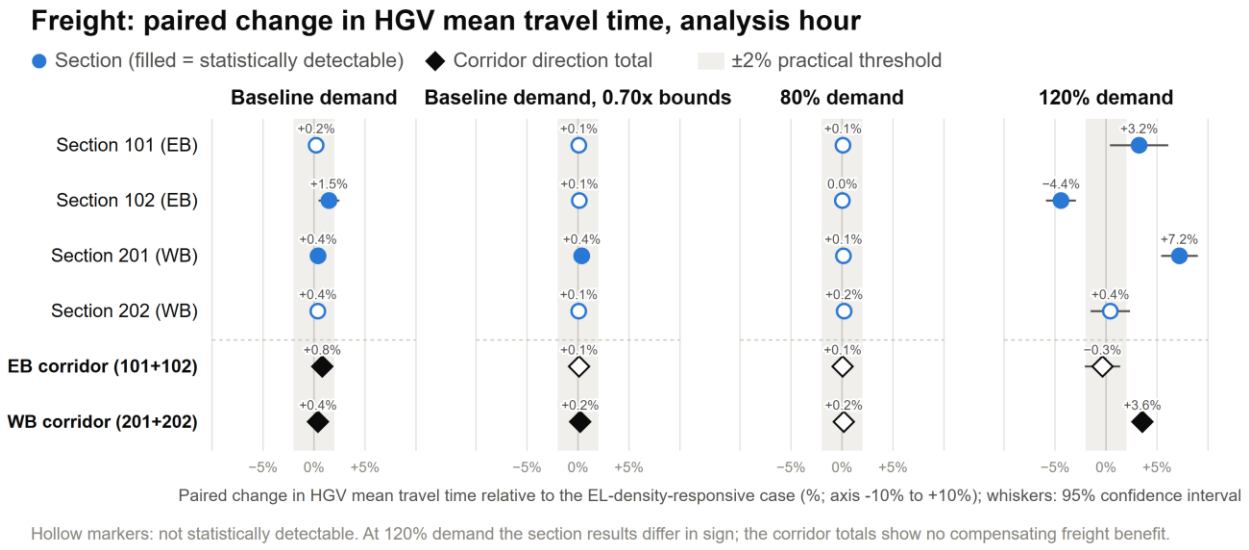

Figure 114. Freight Effects by HGV Section and Corridor Direction

HGV effects were negligible with reduced bounds and at 80% demand and localized at baseline (Section 102 +1.5%). At 120% demand the section results differ in sign, with no compensating corridor benefit (EB -0.3% (n.s.), WB +3.6%).

S.H Positive-feedback diagnostic

Table 109. GP-Responsive Pricing: Positive-Feedback Diagnostic by Comparison

Comparison	EL share falls	GP density rises EB / WB	GP LOS worse / better (of 324)	Tolls above comparator (of 540)	Full chain observed	Classification
GP_RESP vs S1	yes	+3.4% / +2.7%	19 / 0	400	13	WEAK FEEDBACK
GP_RESP_LOW vs S2_LOW	yes	+2.6% / +2.0%	13 / 2	305	3	WEAK FEEDBACK
GP_RESP_D80 vs D80_ELController	yes	+0.7% / +1.2%	2 / 2	328	0	WEAK FEEDBACK
GP_RESP_D120 vs D120	yes	+7.3% / +4.6%	28 / 3	442	53	WEAK FEEDBACK

Time-ordered detail at 120% demand (paired changes against D120 in the 15 minutes after each update; the toll set at update t applies from t to t + 900 s):

Table 110. GP-Responsive Pricing: Time-Ordered Toll and Traffic Response at 120% Demand

Direction	Toll update	Mean segment toll, GP_RESP_D120	Mean segment toll, D120	EL transactions next 15 min	GP density next 15 min	GP travel time next 15 min
EB	900 s	$0.587	$0.575	-2.3%	-	-
EB	1,800 s	$1.614	$0.576	-44.0%	+2.6%	0.0%
EB	2,700 s	$1.781	$0.583	-51.0%	+4.1%	+1.2%
EB	3,600 s	$2.356	$0.593	-77.1%	+7.8%	+1.1%
EB	4,500 s	$2.830	$0.600	-	+12.0%	-2.5%
WB	900 s	$0.670	$0.640	-0.1%	-	-
WB	1,800 s	$1.158	$0.640	-17.8%	+1.6%	+0.1%
WB	2,700 s	$1.452	$0.643	-14.9%	+2.2%	+1.6%
WB	3,600 s	$2.185	$0.650	-52.4%	+4.1%	+3.8%
WB	4,500 s	$2.632	$0.649	-	+9.5%	+8.1%

GP section throughput, all vehicles, analysis hour, GP_RESP_D120 vs D120 (Sections 101 / 102 / 201 / 202): +17.3% / +6.4% / +2.8% / +2.9%. Toll trajectories with repeated reversals in the four GP-responsive scenarios: 0 of 432.

S.I Horizon sufficiency and toll oscillation

Table 111. GP-Responsive Pricing: Horizon Sufficiency and Toll Oscillation

Scenario	Density peaks in final unpriced 15 min (of 108)	Hypothetical 5,400-s update changes toll (of 108)	Up / down	Toll oscillation	Horizon
GP_RESP	15	54	2 / 52	no	SUFFICIENT
GP_RESP_LOW	13	38	0 / 38	no	SUFFICIENT
GP_RESP_D80	3	47	0 / 47	no	SUFFICIENT
GP_RESP_D120	45	54	28 / 26	no	PARTIALLY SUFFICIENT
S1	33	7	2 / 5	no	SUFFICIENT
D80_ELController	17	0	0 / 0	no	SUFFICIENT
D120	81	19	15 / 4	no	PARTIALLY SUFFICIENT

At 120% demand a hypothetical update at 5,400 s would have changed 54 of 108 (28 / 26) segment tolls.

S.J 120% demand: actual tolls by segment and the pre-run indications

Table 112. GP-Responsive Pricing: Actual Tolls by Segment at 120% Demand

Segment	GP_RESP_D120 max	Controller LOS reached (60 updates)	LOS-F band	D120 max
1 EB Lake Mary - 417 Eg	$0.50	A 12, C 24, D 24	$1.30-$1.80	$0.25
2 EB 417 Eg - 417 In	$0.40	A 12, B 26, C 22	$2.30-$3.20	$0.30
3 EB 417 In - Dirksen	$7.50	B 12, C 1, D 23, E 10, F 14	$5.85-$8.20	$0.70
4 EB Dirksen - OCR	$4.30	A 12, D 48	$10.90-$15.25	$1.15

Table 112. GP-Responsive Pricing: Actual Tolls by Segment at 120% Demand (continued)

Segment	GP_RESP_D120 max	Controller LOS reached (60 updates)	LOS-F band	D120 max
5 WB OCR - Dirksen	$7.40	B 12, C 5, D 35, E 8	$10.40-$14.50	$1.10
6 WB Dirksen - 417	$4.75	A 12, C 24, D 12, E 12	$7.05-$9.80	$0.75
7 WB 417 - 46A	$0.35	A 12, B 48	$2.90-$4.00	$0.30
8 WB 46A - Lake Mary	$1.50	B 12, C 19, D 29	$3.75-$5.20	$0.40
9 WB Lake Mary - I-4	$2.40	A 12, C 22, D 26	$6.15-$8.55	$0.70

Maximum tolls: segment $7.50 (Segment 3, 4,500-s update, seeds 2222 and 13332); facility $15.40 (decision point 72, 4,500-s update, seed 4444). Pre-run screening indicated possible tolls of about $8.20 (Segment 3) and $9.80 (Segment 6), the LOS-F ceilings of those segments. Segment 3 reached LOS F but its toll stayed inside the LOS-F band because the controller moves the toll from its previous value in delta-table steps. Segment 6 never reached LOS F.

S.K Implementation validation and quality control

- **Detector neutrality:** with the 296 GP detectors installed and the existing controller active, the control simulation for seed 2222 matched the approved S1 simulation (438 of 438 compared metrics, all results-database tables and 150 of 150 tolls identical).
- **Controller replay:** 16,500 of 16,500 toll observations across the nine scenarios were reproduced exactly from the measured detector data.
- **Runs:** 60 of 60 runs of the GP-responsive batches and the 80% control completed. Paired arms were identical until the first differing toll update.
- **Independent quality control:** baseline analysis 22 of 22 checks, extension analysis 33 of 33 checks passed. The final-report QC (`GP_RESPONSIVE_FINAL_REPORT_QC.md`) recomputes every main-report value from the raw simulation outputs.

Table 113. GP-Responsive Pricing: Controller Replay: Toll Observations Reproduced by Scenario

Scenario	Toll observations	Reproduced exactly	Not reproduced	Runs complete
S1	1,950	1,950	0	12 of 12
S2_LOW	1,800	1,800	0	12 of 12
S2_HIGH	1,950	1,950	0	12 of 12
GP_RESP	1,800	1,800	0	12 of 12
GP_RESP_LOW	1,800	1,800	0	12 of 12
D80_ELController	1,800	1,800	0	12 of 12
GP_RESP_D80	1,800	1,800	0	12 of 12
D120	1,800	1,800	0	12 of 12
GP_RESP_D120	1,800	1,800	0	12 of 12

Warnings in the four extension batches (counts over 12 seeds):

Table 114. GP-Responsive Pricing: Non-Fatal Warnings in the Four Extension Batches

Warning type (12 seeds)	GP_RESP_LOW	D80_ELController	GP_RESP_D80	GP_RESP_D120
decision-73 travel-time notice	14946	12350	12562	18543
lane-change removal (120 s wait)	5	2	2	51
missed managed-lane route connector	0	0	0	1
missed route connector	2	1	2	4
vehicle input not finished	36	12	12	90

The missed-connector warnings are isolated single-vehicle routing events. No warning type recurred at one location in three or more seeds, and none is associated with anomalous outputs. Under the project rule (complete run, intact outputs, isolated non-critical warning: document, do not discard), every run was retained.

S.L Supporting documents

Table 115. GP-Responsive Pricing: Supporting Documents

Topic	Document
Baseline GP-responsive validation and analysis	`Task4_Pricing\GP_Responsive\Run12_Analysis\GP_RESPONSIVE_RUN12_VALIDATION.md`, `GP_RESPONSIVE_RUN12_FULL_ANALYSIS.md`, `GP_RESPONSIVE_TASK42_INTERPRETATION.md`
Detector-neutrality control	`Task4_Pricing\GP_Responsive\PACKAGE_A_COMPLETED_VALIDATION.md`
Extension validation, analysis, QC and recommendation	`Task4_Pricing\GP_Responsive\Screening_Extensions\Run12_Final_Analysis\` (nine reports, 13 CSVs)
Task 4.2 bound sensitivities	`Task4_Pricing\S2_HIGH_12RUN_FINAL_VALIDATION.txt`, `S1_vs_S2_LOW_PAIRED_METRICS.csv`, `S1_vs_S2_HIGH_PAIRED_METRICS.csv`

Final Freeze Note (2026-10-30)

Analysis frozen: 2026-10-30

```
ANALYSIS STATUS:
FINAL / FROZEN

ADDITIONAL VISSIM RUNS:
NOT RECOMMENDED

CURRENT FORMULATION:
NO FURTHER DEVELOPMENT WITHIN THIS STUDY
```

Final scenario classifications (pre-established rules)

Table 116. GP-Responsive Pricing: Final Scenario Classifications

Comparison	Classification
GP_RESP vs S1	NOT PROMISING
GP_RESP_LOW vs S2_LOW	OPERATIONALLY NEUTRAL
GP_RESP_D80 vs D80_ELController	OPERATIONALLY NEUTRAL
GP_RESP_D120 vs D120	MIXED-TRADEOFF (pre-established section-level methodology; the corridor-level HGV result, EB -0.3% (n.s.) and WB +3.6%, is supplementary interpretation only)

Final overarching conclusion

No demonstrated operational advantage; no further testing of the current GP-responsive formulation is recommended.

The controller was technically valid, and GP-density input made pricing substantially more responsive. The stronger responsiveness affected tolls, lane choice and revenue but produced no consistent operational or freight benefit:

- reduced toll bounds created no advantage over the corresponding EL-responsive case;
- lower demand produced no measurable operational benefit;
- elevated demand produced adverse GP and network effects and a mixed freight response.

Final recommendation

STOP: retain the results as Task 4.2 sensitivity evidence. No further VISSIM runs are recommended for the current GP-responsive formulation: no further sensitivity runs, longer-horizon runs, additional seeds or controller variants unless the FDOT project team explicitly reopens the analysis.

Final report files (`Task4_Pricing\GP_Responsive\Final_Report_Material\`)

Table 117. GP-Responsive Pricing: Final Report Package Files

File	Content
`GP_RESPONSIVE_FINAL_REPORT_SECTION.md`	GP-responsive report section (reproduced as Sections S.1-S.9)
`GP_RESPONSIVE_FINAL_REPORT_EXECUTIVE_SUMMARY.md`	One-page summary with the analysis status
`GP_RESPONSIVE_FINAL_REPORT_TABLES.md` and `GP_RESPONSIVE_TABLE_X1/X2/X3_*.csv`	Main-report tables (Markdown and CSV)
`GP_RESPONSIVE_FIGURE_CAPTIONS.md` and `figures\`	Captions; figures as SVG and 3x PNG
`GP_RESPONSIVE_TECHNICAL_APPENDIX.md` and `GP_RESPONSIVE_TABLE_A1_*.csv`	Supporting detail (reproduced as Sections S.A-S.L)
`GP_RESPONSIVE_REPORT_SOURCE_TRACEABILITY.md`	Source of every reported value

Table 117. GP-Responsive Pricing: Final Report Package Files (continued)

File	Content
GP_RESPONSIVE_FINAL_REPORT_QC.md	Final consistency QC with the freeze verdict
GP_RESPONSIVE_FINAL_FREEZE_NOTE.md	This note
report_facts.json	Machine-readable values used by the build and the QC

The pre-freeze version of the package is kept, unchanged, in `_archive\pre_freeze_2026-10-30\` for provenance; it is not for integration.

Appendix T. Future Demand Technical Analysis

About this appendix. This appendix reproduces the frozen Subtask 4.3 technical appendix, which supports Part V, Chapter 2. Text and values are unchanged; its sections are numbered T.1-T.12 and its tables are numbered and captioned for this report.

Supporting detail for Part V, Chapter 2. All values come from the validated 12-seed analysis in `Task4_Demand\` (four-level synthesis `TASK43_DEMAND_SENSITIVITY_FINAL_ANALYSIS.md` and the per-level paired files); percentages are rounded once from full precision.

T.1 Run set and exclusions

Table 118. Future Demand: Run Set and Exclusions

Scenario	Valid paired runs	Seeds	Excluded run
S1	12	2222-14443 (runs _002-_013)	_001: standalone seed-2222 check, identical to _002
D110	12	2222-14443 (runs _001-_012)	none
D120	12	2222-14443 (runs _001-_012)	none
D130	12	2222-14443 (runs _002-_013)	_001: earlier attempt ended at 3,035.7 s; replaced by _002 (same seed, complete)

All 48 paired runs reached 5,400 s with complete managed-lane, travel-time and database outputs and no error, fatal, Python, COM, database or toll message. Non-fatal warnings rise with demand (mean per run, S1 / D110 / D120 / D130): inputs not finished 3.0 / 3.2 / 7.3 / 14.4; lane-change removals 0.5 / 0.3 / 3.6 / 10.3; missed route connectors 0 / 0.1 / 0.2 / 0.8. The seed-2222 run of each batch reproduces the corresponding validated screening run exactly. Source: per-level `D1x0_12RUN_FINAL_VALIDATION.md`; `S1_ANALYSIS_12RUN_FINAL_VALIDATION.txt`.

T.2 Demand implementation

Table 119. Future Demand: Demand Implementation by Scenario

Scenario	Factor	Requested vehicles, 0-5,400 s (full precision)	HGV share
S1	1.00	116,159.25	2.44%
D110	1.10	127,775.175	2.44%
D120	1.20	139,391.100	2.44%
D130	1.30	151,007.025	2.44%

330 EXACT vehicle-input volumes (66 inputs x 5 intervals) scaled with exact decimal arithmetic; INPX otherwise unchanged except the number of runs. Source: `DEMAND_INPUT_CHANGE_DETAIL.csv`; `TASK43_DEMAND_SCENARIO_IMPLEMENTATION_AUDIT.txt`.

T.3 Demand loading detail

Table 120. Future Demand: Demand Loading Detail

Scenario	Realized increase, mean [95% CI]	Added requested demand realized: cumulative / step	Unserved (% of requested)
D110	+9.57% [9.52, 9.62]	94.9% / 94.9%	1,596 (1.25%)
D120	+18.77% [18.71, 18.83]	93.0% / 91.2%	2,617 (1.88%)
D130	+26.87% [26.75, 26.98]	88.8% / 80.3%	4,910 (3.25%)

Entry points with the largest unserved demand (12-seed mean vehicles; seeds with any unserved vehicles):

Table 121. Future Demand: Entry Points with the Largest Unserved Demand

Scenario	Vehicle input	Unserved, mean	Seeds
D110	Input 72 (link 748)	1,119.4	12 of 12
D110	Input 60 (link 5)	260.7	12 of 12
D110	Input 73 (link 746)	208.3	12 of 12
D110	Input 26 (link 364)	7.5	1 of 12
D110	Input 1 (link 63, F-63)	0.3	1 of 12
D120	Input 72 (link 748)	1,389.0	12 of 12
D120	Input 60 (link 5)	443.2	12 of 12
D120	Input 73 (link 746)	339.8	12 of 12
D120	Input 26 (link 364)	187.9	12 of 12
D120	Input 37 (link 291)	122.0	12 of 12
D120	Input 34 (link 335)	95.3	12 of 12
D130	Input 72 (link 748)	1,659.7	12 of 12
D130	Input 60 (link 5)	644.3	12 of 12
D130	Input 73 (link 746)	447.4	12 of 12
D130	Input 26 (link 364)	425.6	12 of 12
D130	Input 37 (link 291)	342.4	12 of 12
D130	Input 4 (link 2)	288.3	12 of 12

New entry points with unserved demand that never had any in S1: D110 2, D120 11, D130 19.

T.4 Paired results with 95% confidence intervals

Table 122. Future Demand: Paired Results with 95% Confidence Intervals

Measure	S1 (12-seed mean)	D110 % [95% CI]	D120 % [95% CI]	D130 % [95% CI]	Seeds up/down (D110 / D120 / D130)
EB GP travel time (Sections 101+102)	1,151.72 s	+8.2% [7.4, 9.1]	+22.3% [21.1, 23.5]	+32.0% [30.3, 33.7]	12/0 / 12/0 / 12/0
WB GP travel time (Sections 201+202)	1,050.07 s	+1.6% [1.3, 2.0]	+8.6% [7.6, 9.6]	+14.9% [13.5, 16.3]	12/0 / 12/0 / 12/0
GP travel time, Section 101	598.18 s	+4.1% [3.2, 4.9]	+21.8% [20.6, 23.0]	+31.8% [29.5, 34.0]	12/0 / 12/0 / 12/0
GP travel time, Section 102	553.53 s	+12.7% [11.2, 14.3]	+22.8% [20.7, 25.0]	+32.3% [30.6, 34.1]	12/0 / 12/0 / 12/0

Table 122. Future Demand: Paired Results with 95% Confidence Intervals (continued)

Measure	S1 (12-seed mean)	D110 % [95% CI]	D120 % [95% CI]	D130 % [95% CI]	Seeds up/down (D110 / D120 / D130)
GP travel time, Section 201	487.82 s	+1.2% [1.0, 1.4]	+10.5% [8.7, 12.2]	+20.3% [18.1, 22.6]	12/0 / 12/0 / 12/0
GP travel time, Section 202	562.25 s	+2.0% [1.5, 2.5]	+7.0% [6.2, 7.8]	+10.2% [9.4, 11.1]	12/0 / 12/0 / 12/0
network delay per vehicle	100.15 s/veh	+26.2% [24.7, 27.8]	+78.7% [74.4, 83.1]	+149.1% [145.9, 152.3]	12/0 / 12/0 / 12/0
network total delay	2,226.29 veh-h	+36.8% [35.2, 38.4]	+105.0% [100.4, 109.6]	+196.2% [193.0, 199.4]	12/0 / 12/0 / 12/0
network vehicles arrived	80,030.58 veh	+8.4% [8.2, 8.5]	+14.7% [14.4, 14.9]	+18.9% [18.6, 19.2]	12/0 / 12/0 / 12/0
EB GP throughput (101+102)	2,655.08 veh-sections/h	+2.6% [1.6, 3.6]	+1.3% [-0.0, 2.6]	-2.4% [-3.9, -0.9]	12/0 / 10/2 / 2/10
WB GP throughput (201+202)	4,032.25 veh-sections/h	+8.6% [8.3, 8.9]	+10.4% [7.0, 13.7]	+9.1% [7.8, 10.3]	12/0 / 11/1 / 12/0
EB EL travel time (501-504)	553.80 s	+0.7% [0.5, 0.8]	+1.6% [1.3, 1.8]	+2.7% [2.3, 3.0]	12/0 / 12/0 / 12/0
WB EL travel time (505-509)	754.56 s	+0.1% [-0.1, 0.3]	+0.3% [0.2, 0.5]	+0.5% [0.3, 0.6]	8/4 / 11/1 / 12/0
EB EL space-mean speed	67.17 mph	-0.8% [-1.0, -0.6]	-1.9% [-2.2, -1.6]	-3.5% [-3.8, -3.1]	0/12 / 0/12 / 0/12
WB EL space-mean speed	70.65 mph	-0.1% [-0.3, 0.1]	-0.4% [-0.5, -0.2]	-0.5% [-0.7, -0.3]	4/8 / 1/11 / 1/11
EB EL throughput	4,984.08 veh-sections/h	+14.9% [13.9, 15.9]	+32.3% [30.5, 34.1]	+51.3% [49.4, 53.2]	12/0 / 12/0 / 12/0
WB EL throughput	3,600.92 veh-sections/h	+9.7% [9.1, 10.2]	+21.5% [20.2, 22.8]	+31.3% [29.3, 33.2]	12/0 / 12/0 / 12/0
HGV mean travel time, EB (101+102)	1,197.49 s	+10.0% [8.6, 11.4]	+29.0% [26.2, 31.8]	+40.2% [37.1, 43.3]	12/0 / 12/0 / 12/0
HGV mean travel time, WB (201+202)	1,079.90 s	+3.0% [1.9, 4.2]	+13.2% [11.4, 14.9]	+23.4% [20.9, 25.9]	12/0 / 12/0 / 12/0
HGV mean travel time, Section 101	621.96 s	+6.0% [4.2, 7.8]	+32.0% [27.6, 36.4]	+45.2% [38.8, 51.7]	12/0 / 12/0 / 12/0
HGV mean travel time, Section 102	575.53 s	+14.3% [12.1, 16.6]	+25.8% [22.2, 29.5]	+34.8% [32.0, 37.5]	12/0 / 12/0 / 12/0
HGV mean travel time, Section 201	500.51 s	+1.5% [1.2, 1.9]	+12.9% [10.6, 15.3]	+26.2% [23.5, 28.8]	12/0 / 12/0 / 12/0
HGV mean travel time, Section 202	579.39 s	+4.3% [2.3, 6.4]	+13.3% [10.7, 15.9]	+21.0% [18.3, 23.7]	12/0 / 12/0 / 12/0

Table 122. Future Demand: Paired Results with 95% Confidence Intervals (continued)

Measure	S1 (12-seed mean)	D110 % [95% CI]	D120 % [95% CI]	D130 % [95% CI]	Seeds up/down (D110 / D120 / D130)
network delay per HGV	111.37 s/veh	+28.9% [25.3, 32.4]	+92.4% [86.3, 98.6]	+171.2% [163.6, 178.8]	12/0 / 12/0 / 12/0
toll transactions	3,160.42 veh	+11.3% [10.5, 12.2]	+22.9% [21.7, 24.2]	+37.7% [35.7, 39.7]	12/0 / 12/0 / 12/0
average toll paid	$0.94	+0.9% [0.6, 1.3]	+2.7% [2.3, 3.1]	+5.0% [4.5, 5.5]	11/1 / 12/0 / 12/0
toll revenue	$2,969.60	+12.4% [11.3, 13.4]	+26.2% [24.7, 27.7]	+44.6% [42.3, 46.9]	12/0 / 12/0 / 12/0
EL share at the toll decision points	0.1840	+2.2% [1.5, 2.9]	+5.7% [5.1, 6.4]	+11.1% [10.3, 11.9]	11/1 / 12/0 / 12/0

Paired 12-seed mean differences relative to S1 divided by the S1 mean; CI from the paired t distribution (11 degrees of freedom). EL share is the fraction at the toll decision points; its percentage change is computed at full precision (D120: +5.733%).

T.5 Paired steps between demand levels

Table 123. Future Demand: Paired Steps Between Demand Levels

Measure	S1 -> D110	D110 -> D120	D120 -> D130
network vehicles arrived	+8.4%	+5.8%	+3.7%
EB GP travel time (Sections 101+102)	+8.2%	+13.0%	+8.0%
WB GP travel time (Sections 201+202)	+1.6%	+6.9%	+5.8%
network delay per vehicle	+26.2%	+41.6%	+39.4%
HGV mean travel time, EB (101+102)	+10.0%	+17.3%	+8.6%

Step = mean paired change from the previous level, as a percentage of the previous level's mean, computed from the per-seed differences.

T.6 Seed-level results

Table 124. Future Demand: Seed-Level Results

Seed	Realized increase D110	D120	D130	EB GP travel time change (s) D110	D120	D130	Network delay per vehicle change (s/veh) D110	D120	D130
2222	9.61%	18.57%	26.57%	108.5	247.2	392.5	29.1	76.4	152.5
3333	9.64%	18.89%	27.04%	103.3	284.6	410.7	22.7	77.0	142.4
4444	9.45%	18.83%	27.03%	79.8	234.1	352.2	23.3	72.3	147.9
5555	9.60%	18.78%	26.96%	79.2	226.0	367.7	24.7	74.5	143.9
6666	9.58%	18.73%	26.75%	104.1	260.6	346.4	28.4	78.0	147.5
7777	9.56%	18.77%	27.13%	98.7	266.5	369.1	28.1	79.2	146.4
8888	9.54%	18.92%	26.78%	101.0	257.2	339.2	28.9	85.5	160.4
9999	9.46%	18.80%	26.74%	79.0	262.1	338.7	24.2	97.4	152.8
11110	9.64%	18.70%	26.89%	119.3	301.5	415.8	29.6	81.6	155.0

Table 124. Future Demand: Seed-Level Results (continued)

Seed	Realized increase D110	D120	D130	EB GP travel time change (s) D110	D120	D130	Network delay per vehicle change (s/veh) D110	D120	D130
12221	9.49%	18.74%	27.11%	70.6	237.2	327.4	25.7	76.9	147.5
13332	9.61%	18.73%	26.67%	113.1	270.6	408.6	26.3	73.8	147.3
14443	9.66%	18.78%	26.71%	82.0	233.8	360.3	24.3	73.6	148.2

T.7 15-minute evolution (% change vs S1)

Table 125. Future Demand: 15-Minute Evolution of Selected Measures (% Change vs. S1)

Measure	1,800-2,700 s	2,700-3,600 s	3,600-4,500 s	4,500-5,400 s
EB GP travel time (Sections 101+102), D110	+1.2%	+2.8%	+8.9%	+19.7%
EB GP travel time (Sections 101+102), D120	+2.8%	+8.6%	+29.9%	+52.2%
EB GP travel time (Sections 101+102), D130	+6.4%	+18.5%	+49.0%	+66.3%
WB GP travel time (Sections 201+202), D110	+0.5%	+0.9%	+1.5%	+3.3%
WB GP travel time (Sections 201+202), D120	+1.2%	+3.2%	+9.7%	+21.5%
WB GP travel time (Sections 201+202), D130	+1.9%	+6.2%	+18.9%	+34.3%
HGV mean travel time, EB (101+102), D110	+1.3%	+4.1%	+9.7%	+22.3%
HGV mean travel time, EB (101+102), D120	+3.4%	+10.3%	+36.3%	+61.4%
HGV mean travel time, EB (101+102), D130	+7.9%	+23.0%	+61.4%	+84.0%
EB EL travel time (501-504), D110	+0.1%	+0.9%	+0.5%	+1.0%
EB EL travel time (501-504), D120	+0.8%	+1.1%	+1.4%	+2.5%
EB EL travel time (501-504), D130	+0.9%	+1.1%	+2.2%	+5.2%

T.8 Freight reliability (pooled 12-seed HGV records, analysis hour)

Table 126. Future Demand: Freight Reliability (Pooled 12-Seed HGV Records, Analysis Hour)

Section	S1 P95	D110	D120	D130
Section 101	670.1 s (n 215)	754.8 s (+12.6%; diff CI [52.2, 125.5] s; BI 0.146; PTI 1.380)	1,184.0 s (+76.7%; diff CI [475.9, 533.4] s; BI 0.437; PTI 2.165)	1,348.7 s (+101.3%; diff CI [616.9, 720.1] s; BI 0.510; PTI 2.467)
Section 102	648.7 s (n 759)	852.6 s (+31.4%; diff CI [178.7, 227.1] s; BI 0.294; PTI 1.743)	946.8 s (+45.9%; diff CI [273.3, 345.5] s; BI 0.308; PTI 1.936)	1,012.7 s (+56.1%; diff CI [340.0, 396.5] s; BI 0.306; PTI 2.071)
Section 201	529.6 s (n 1237)	540.2 s (+2.0%; diff CI [4.7, 17.2] s; BI 0.063; PTI 1.162)	692.3 s (+30.7%; diff CI [139.2, 184.6] s; BI 0.225; PTI 1.489)	871.6 s (+64.6%; diff CI [317.6, 358.2] s; BI 0.383; PTI 1.875)
Section 202	612.7 s (n 288)	682.2 s (+11.3%; diff CI [36.1, 114.1] s; BI 0.129; PTI 1.242)	843.2 s (+37.6%; diff CI [194.2, 253.5] s; BI 0.284; PTI 1.534)	938.6 s (+53.2%; diff CI [256.4, 359.0] s; BI 0.339; PTI 1.708)

BI = buffer index; PTI = planning time index (S1 free-flow reference). Every P95 change has a seed-pair bootstrap 95% confidence interval that excludes zero. 15-minute reliability for Sections 102 and 201: `TASK43_DEMAND_SENSITIVITY_FINAL_ANALYSIS.md`, section 7.

T.9 Controller detail

Table 127. Future Demand: Controller Detail by Demand Level

Indicator	S1	D110	D120	D130
Toll updates at LOS A / B / C / D or worse (of 540)	474 / 66 / 0 / 0	441 / 99 / 0 / 0	412 / 120 / 8 / 0	384 / 129 / 27 / 0
At the segment LOS-A toll	96.1%	90.6%	85.7%	81.1%
Strictly inside a LOS band (interior)	5	1	2	4
Toll changes between successive updates / of which > $0.05	24 / 0	30 / 0	37 / 0	48 / 9
Most toll levels on a segment; largest within-run toll range	2; $0.05	2; $0.05	2; $0.05	3; $0.30
Final tolls depending on the density-change step size (x0.1 or x10)	1 (0.19%)	1 (0.19%)	1 (0.19%)	12 (2.22%)
Segment-intervals at LOS C or worse (of 648)	0	1	32	63

Table 127. Future Demand: Controller Detail by Demand Level (continued)

Indicator	S1	D110	D120	D130
Tolls reproduced from detector data (segment tolls, 0-4,500 s)	648 of 648	648 of 648	648 of 648	648 of 648
Pooled classification	effectively fixed	weakly dynamic	weakly dynamic	weakly dynamic

The density-change table is material if more than 4% of final tolls depend on its step size; no level exceeds that (D130 2.22%).

T.10 Simulation horizon

Table 128. Future Demand: Simulation Horizon Indicators

Indicator	S1	D110	D120	D130
Segment-seeds whose highest EL density falls in 4,500-5,400 s (of 108)	33 (31%)	66 (61%)	81 (75%)	83 (77%)
Offline 5,400-s update: tolls changed (of which up)	7 (2)	16 (11)	19 (15)	40 (37)
Offline 5,400-s update: changed by more than $0.05	0	0	12	25
Offline 5,400-s update: largest increase	$0.05	$0.05	$0.25	$1.35
Horizon for interpreting the late pricing response	-	sufficient	partially sufficient	limiting

The offline update applies the unchanged controller to the 4,500-5,400-s densities. It is not a simulation result: no traffic responds to it.

T.11 Revenue decomposition (12-seed means, 0-4,500 s)

Table 129. Future Demand: Revenue Decomposition (12-Seed Means, 0-4,500 s)

Scenario	Revenue change vs S1 ($)	From more transactions at S1 tolls ($)	From higher tolls ($)	Share from higher tolls
D110	+367.27	+352.25	+15.02	4.1%
D120	+778.54	+747.80	+30.74	3.9%
D130	+1,324.80	+1,256.15	+68.65	5.2%

T.12 Validation and quality control

- Scenario integrity per level: INPX differs from S1 only in the scaled volumes; controller files byte-identical; HGV lane restrictions unchanged.

- Controller replay: 7,200 simulated tolls reproduced from detector data.
- Independent QC of the four-level deliverables: 250 of 250 checks passed (`TASK43_DEMAND_FINAL_QC.txt`).
- HGV exclusion: 0 HGV observations on Express Lane detectors, sections and links in all 48 runs.

Appendix U. Incident Analysis Technical Details

About this appendix. This appendix provides the technical detail supporting the incident analysis in Part III, Chapter 5: latent delay, the qualitative grouping of incident effects, the coded scenario configuration, seed-level paired results, the comparison with previously reported values, the corrected PM SC03 implementation check, and comparable-section travel times for passenger vehicles and HGVs. All values are paired changes relative to a no-incident reference run with the same random seed and VISSIM version.

U.1 Latent Delay and Expanded System Impact

Latent delay is the VISSIM network-performance output for the total waiting time of vehicles that could not enter the network at their vehicle inputs during an evaluation interval; latent demand is the corresponding number of waiting vehicles. Both are native outputs. The latent-delay change reported in Table 130 is the difference between the incident run and its same-seed reference, averaged over the four hourly intervals. The expanded system impact is derived by adding this change to the in-network delay change for the same seed; it is not a native VISSIM output and is reported only where the latent-delay change is large and consistent across seeds (SC07).

Table 130. SC07 In-Network, Latent and Expanded Delay Effects (veh-h per interval)

Period	Seed	In-network delay Δ (native)	Latent delay Δ (native output; change derived)	Expanded system impact (derived)
AM	Smaller Seed	+556.18	+580.79	+1136.97
AM	Larger Seed	+503.04	+419.70	+922.74
AM	Mean	+529.61	+500.24	+1029.85
PM	Smaller Seed	+347.60	+1133.60	+1481.20
PM	Larger Seed	+462.58	+1095.05	+1557.63
PM	Mean	+405.09	+1114.32	+1519.42

Note: All values are paired changes relative to the same-seed, same-version reference, averaged over the four hourly intervals. The expanded system impact is the sum of the two preceding columns and is a derived measure.

U.2 Qualitative Grouping of Incident Effects

Table 131 groups the incident effects using the incident-window change in in-network delay on both paired seeds, as defined in the Comparison Methodology section of Part III, Chapter 5. The groups are descriptive and are not statistical tests.

Table 131. Qualitative Grouping of Incident Effects

Effect group	AM peak	PM peak	Basis (incident-window delay change, both seeds)
Severe	SC07	SC07	At least about 400 veh-h on both seeds; large, consistent latent-delay increase
Clear / moderate	SC03; SC05 (seed-sensitive magnitude)	SC03 (corrected)	At least 50 veh-h on both seeds
Moderate in incident window; small full-run net effect	SC06	SC06	At least 50 veh-h on both seeds in the incident window; full-run effect of mixed sign
Small	SC01; SC02B	SC05	10 to 50 veh-h on both seeds, same sign
Negligible	SC02; SC04; SC08	SC02; SC04; SC08	Below 10 veh-h on both seeds
Uncertain / not available	-	SC01 (no clear incident effect); SC02B (no usable output)	Mixed sign; no output

U.3 Incident Scenario Configuration

Table 132 lists the coded configuration of each incident scenario. Positions are measured along the link from its upstream end; lane 1 is the rightmost lane. Each reduced-speed area applies the same speed distribution to cars and HGVs. The friction/rubbernecking distribution is 8 to 18 mph in the AM model and 5 to 15 mph in the PM model.

Table 132. Incident Scenario Configuration

Scenario	Facility (link)	Lanes and reduced speed	Location on link	Active period (s)
SC01	I-95 NB GP, link 109 (5 lanes)	lane 1: 25 mph (25-28 mph)	lane 1: 1,500-1,700 ft	4,500-6,300
SC02	I-95 NB GP, link 112 (4 lanes)	lane 1: 3 mph	lane 1: 164-264 ft	3,600-5,400
SC02B	I-95 NB GP, link 112 (4 lanes)	lane 1: 3 mph; lane 2: friction	lane 1: 164-264 ft; lane 2: 98-394 ft	3,600-5,400
SC03	I-95 NB GP, link 109 (5 lanes)	lane 1: 3 mph; lane 2: 3 mph; lane 3: friction	lane 1: 1,500-1,700 ft; lane 2: 1,500-1,700 ft; lane 3: 1,400-1,700 ft	3,000-5,400
SC04	I-95 NB EL, link 304 (2 lanes)	lane 1: 3 mph	lane 1: 1,312-1,640 ft	4,200-6,000
SC05	I-95 NB on-ramp from IDR, link 158 (1 lane)	lane 1: 15 mph (15-18 mph)	lane 1: 7-171 ft	3,600-5,100
SC06	I-95 NB GP, link 103 (4 lanes)	lane 1: 3 mph; lane 2: friction	lane 1: 984-1,148 ft; lane 2: 656-1,312 ft	4,800-6,600
SC07	I-95 SB GP, link 204 (5 lanes)	lane 1: 3 mph; lane 2: 3 mph; lane 3: friction	lane 1: 328-984 ft; lane 2: 328-984 ft; lane 3: 262-1,181 ft	2,700-9,000
SC08	I-95 SB GP, link 216 (3 lanes)	lane 1: friction	lane 1: 13-505 ft	AM 6,200-7,800; PM 7,500-9,000

U.4 Paired Results by Seed

Table 133 and Table 134 give the paired changes for each seed. Delay and latent-delay changes are in veh-h per hourly interval; the incident-window change is summed over 1,800 to 9,000 seconds; car and HGV changes are in average delay per vehicle.

Table 133. AM Peak — Paired Incident Effects by Seed

Scenario	Seed	Delay Δ (veh-h per interval)	Incident-window Δ (veh-h)	Avg speed Δ (mph)	Car delay per vehicle Δ (%)	HGV delay per vehicle Δ (%)	Latent delay Δ (veh-h per interval)
SC01	42	+13.83	+32.66	−0.15	+1.5%	+1.9%	+3.15
SC01	47	+21.62	+24.94	−0.20	+1.9%	+2.8%	−49.40
SC02	42	+1.13	+4.52	−0.03	+0.1%	+0.2%	0.00
SC02	47	+1.61	+6.44	−0.04	+0.2%	+0.4%	0.00
SC02B	42	+6.62	+26.48	−0.14	+0.8%	+1.4%	0.00
SC02B	47	+10.20	+40.82	−0.19	+0.8%	+2.0%	0.00
SC03	42	+105.50	+201.11	−1.49	+13.5%	+15.0%	+2.39
SC03	47	+70.93	+174.10	−0.96	+6.8%	+9.4%	−22.74
SC04	42	+0.10	+0.41	−0.01	0.0%	0.0%	0.00
SC04	47	+0.10	+0.41	−0.01	0.0%	0.0%	0.00
SC05	42	+149.20	+223.34	−1.85	+19.2%	+17.1%	+40.22
SC05	47	+36.17	+77.78	−0.43	+3.5%	+3.9%	+17.23
SC06	42	−18.08	+183.19	+0.44	−3.3%	−3.3%	+54.63
SC06	47	+33.57	+99.76	−0.35	+3.2%	+6.9%	+10.07
SC07	42	+556.18	+544.00	−6.67	+73.5%	+109.6%	+580.79
SC07	47	+503.04	+420.99	−5.33	+51.6%	+88.4%	+419.70
SC08	42	+0.17	+0.69	−0.01	0.0%	0.0%	0.00
SC08	47	−0.16	−0.65	0.00	0.0%	0.0%	0.00

Table 134. PM Peak — Paired Incident Effects by Seed

Scenario	Seed	Delay Δ (veh-h per interval)	Incident-window Δ (veh-h)	Avg speed Δ (mph)	Car delay per vehicle Δ (%)	HGV delay per vehicle Δ (%)	Latent delay Δ (veh-h per interval)
SC01	42	−40.93	+0.29	+0.40	−4.1%	−2.9%	+28.08
SC01	47	−40.16	−19.97	+0.47	−4.3%	−8.6%	−8.25
SC02	42	+1.13	+4.50	−0.02	+0.1%	+0.2%	0.00
SC02	47	+1.37	+5.49	−0.03	+0.1%	+0.2%	0.00
SC03	42	+44.15	+159.94	−0.64	+3.7%	+5.3%	−70.11
SC03	47	+82.07	+349.72	−1.23	+8.7%	+6.8%	+51.66
SC04	42	+0.09	+0.37	−0.01	0.0%	0.0%	0.00
SC04	47	+0.07	+0.28	−0.01	0.0%	0.0%	0.00
SC05	42	+3.16	+12.63	−0.05	+0.3%	+0.4%	0.00
SC05	47	−21.05	+16.82	+0.22	−2.2%	−1.4%	+34.76
SC06	42	+53.38	+117.75	−0.71	+5.9%	+6.2%	+2.65
SC06	47	−27.49	+86.59	+0.26	−3.1%	−2.7%	+14.36
SC07	42	+347.60	+727.93	−4.32	+34.2%	+43.1%	+1133.60
SC07	47	+462.58	+819.10	−5.59	+51.0%	+71.6%	+1095.05
SC08	42	+0.43	+1.64	−0.01	0.0%	+0.1%	0.00
SC08	47	+0.47	+1.76	−0.01	0.0%	+0.1%	0.00

U.5 Comparison with Previously Reported Values

The preliminary draft report as originally submitted reported AM incident effects relative to the ten-run average of the reference model and PM incident effects relative to the VISSIM 2023 reference runs. Relative to the paired comparison, the first choice added +74.23 veh-h per interval

to every AM scenario, and the second added −43.37 veh-h per interval for the software version and +48.17 veh-h per interval for the seed selection (net +4.80) to every PM scenario. The earlier PM SC03 run did not contain an active incident (Section U.6). In addition, two PM rows contained transcription errors: SC01 was printed as 4.74 h, 3.7% and −0.29 mph instead of −35.74 h, −3.7% and +0.29 mph, and SC05 as 4.14 h and 0.4% instead of −4.14 h and −0.4%. Table 135 compares the previously reported values with the corrected paired means.

Table 135. Previously Reported and Corrected Network Delay Effects

Period	Scenario	Previously reported delay Δ (h)	Corrected paired mean (veh-h per interval)	Principal reason for change
AM	SC07	603.84	+529.61	Same-seed reference replaces ten-run average (removes +74.23)
AM	SC05	166.91	+92.68	Same-seed reference replaces ten-run average (removes +74.23)
AM	SC03	162.45	+88.22	Same-seed reference replaces ten-run average (removes +74.23)
AM	SC01	91.95	+17.72	Same-seed reference replaces ten-run average (removes +74.23)
AM	SC06	81.98	+7.75	Same-seed reference replaces ten-run average (removes +74.23)
AM	SC02	75.60	+1.37	Same-seed reference replaces ten-run average (removes +74.23)
AM	SC04	74.33	+0.10	Same-seed reference replaces ten-run average (removes +74.23)
AM	SC08	74.23	0.00	Same-seed reference replaces ten-run average (removes +74.23)
PM	SC07	409.90	+405.09	Same-version, same-seed reference (removes version and seed-selection offsets)
PM	SC06	17.75	+12.94	Same-version, same-seed reference (removes version and seed-selection offsets)
PM	SC02	6.05	+1.25	Same-version, same-seed reference (removes version and seed-selection offsets)
PM	SC08	5.25	+0.45	Same-version, same-seed reference (removes version and seed-selection offsets)
PM	SC04	4.88	+0.08	Same-version, same-seed reference (removes version and seed-selection offsets)
PM	SC03	4.80	+63.11	Corrected scenario configuration; earlier value had no active incident
PM	SC05	4.14	−8.95	Printed value should have read −4.14; superseded by same-version paired value
PM	SC01	4.74	−40.54	Printed value should have read −35.74; superseded by same-version paired value

U.6 Corrected PM SC03 Implementation Check

In the preliminary draft report as originally submitted, the PM SC03 reduced-speed areas were not positioned on the intended section of link 109 (they were located at the downstream end of the link with zero length), so the reported PM SC03 values did not reflect an active incident. The scenario was re-coded with the reduced-speed areas at 1,500 ft (lanes 1 and 2, 200 ft long) and 1,400 ft (lane 3, 300 ft long) on link 109, matching the AM SC03 configuration, and re-simulated in VISSIM 2025 with all seeds together with its same-version reference. The corrected and reference runs are identical vehicle by vehicle before the incident starts at 3,000 seconds. During the incident, link 109 delay rises to about 71 to 75 veh-h in the 3,600 to 5,400 second interval (reference below 1 veh-h) and its average speed falls to about 15 mph, with the queue extending upstream through links 11 and 108 (Table 136). No latent-demand effect attributable to the incident was found.

Table 136. Corrected PM SC03: Link 109 Delay and Speed by Half-Hour Interval

Interval (s)	Reference delay, (veh-h)	SC03 delay, (veh-h)	Reference speed, (mph)	SC03 speed, (mph)
1,800-3,600	0.63 / 0.64	12.52 / 13.32	55.9 / 55.9	37.0 / 36.3
3,600-5,400	0.80 / 0.86	70.96 / 74.81	55.7 / 55.6	15.2 / 14.3
5,400-7,200	0.94 / 0.88	7.88 / 13.90	55.5 / 55.6	46.5 / 41.1
7,200-9,000	0.79 / 0.86	0.81 / 13.00	55.8 / 55.7	55.7 / 40.5

U.7 Passenger-Vehicle and HGV Travel Time on Comparable Sections

Table 137 compares the change in section travel time for cars and HGVs on sections and intervals where HGV travel times are recorded in both the incident and the reference run, so that both classes are compared on the same sections. For the corrected PM SC03, the northbound sections passing through the incident are also shown for vehicles completing them during the incident period.

Table 137. Change in Section Travel Time for Cars and HGVs on Comparable Sections

Scenario	Seed	Car travel time Δ (%)	HGV travel time Δ (%)	Basis
AM SC07	42	+160.7%	+166.1%	All sections, intervals with HGV data in both runs
AM SC07	47	+158.6%	+170.1%	All sections, intervals with HGV data in both runs
PM SC07	42	+31.3%	+32.9%	All sections, intervals with HGV data in both runs
PM SC07	47	+65.8%	+67.0%	All sections, intervals with HGV data in both runs
AM SC03	42	+13.3%	+25.9%	All sections, intervals with HGV data in both runs
AM SC03	47	+12.2%	+17.1%	All sections, intervals with HGV data in both runs
PM SC03 (corrected)	42	+8.8%	+13.1%	All sections, intervals with HGV data in both runs
PM SC03 (corrected)	47	+12.8%	+11.6%	All sections, intervals with HGV data in both runs
PM SC03 (corrected)	42	+125.2%	+228.8%	NB sections through the incident, vehicles completing 3,000-5,400 s
PM SC03 (corrected)	47	+150.4%	+171.3%	NB sections through the incident, vehicles completing 3,000-5,400 s