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Literature Review

Sustainability and Efficiency Benefits of Commercial Vehicle Platooning

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Abstract

This study evaluates the impact of dedicating an existing highway lane as an Exclusive Truck Platooning Lane (ETPL). Using real-world traffic data, the analysis highlights operational efficiency and environmental benefits before and after ETPL implementation, focusing on Florida's Strategic Intermodal System (SIS) corridors. The study reallocates the existing rightmost lane, prioritizing freight traffic to improve performance.

Advanced simulation tools such as VISSIM and MOVES, combined with GIS-based spatial analysis, were employed to assess travel time and emissions impacts under various scenarios. These included alternate speeds, traffic volumes, and lane configurations. The results demonstrated that ETPL implementation significantly reduced travel time and emissions for freight trucks. The findings also revealed a minor increase in passenger vehicle travel time; however, the associated costs were negligible compared to the substantial savings achieved through improved freight efficiency. Emission reductions were visualized through GIS-generated heat maps across the study area, with the greatest benefits observed at lower speeds. This methodology provides actionable insights for decision-makers, identifying high-priority corridors for targeted interventions and resource allocation, ultimately enhancing traffic flow and reducing environmental impacts.

Introduction

Commercial freight trucks play a critical role in both the economy of the United States and the condition of the traffic systems they travel on. They transport products and goods across the country, with estimates from the Federal Highway Administration (FHWA) indicating that over 55 million tons of cargo are moved by freight annually, with a total value exceeding $49.3 billion. Even international shipments brought in by air or sea , often rely on freight trucks for the most efficient ground transport.

Freight trucks frequently impact the traffic systems they traverse. Their large size strains roadway capacity, as smaller and faster passenger vehicles maneuver around them. This dynamic increases congestion, leading to longer delays, reduced free-flow speeds, and a heightened risk of collisions.

These challenges are further exacerbated by restrictions placed on trucks, such as speed limits or lane-change restrictions. The environmental effects of freight trucks also warrant consideration. The delays caused by trucks reduce overall fuel efficiency, as passenger vehicles are forced into repeated stop-and-go movements. Furthermore, the greater energy required to move heavier vehicles, and their cargo means freight trucks consume more fuel and burn it at a higher rate. Although trucks account for only about 5% of vehicles on the road, according to the Environmental Protection Agency (EPA), they are responsible for more than 20% of all greenhouse gas emissions in the transportation sector Figure 1.

Although these issues are manageable today, freight trucking is expected to expand alongside population growth. A report by the U.S. Department of Transportation (USDOT) predicts an annual increase in freight trucking of 3.4% until 2024, after which growth is expected to accelerate further. As delays become unsustainable, action must be taken to prevent the complete failure of transportation systems. Since trucks are the primary contributors to these delays, the solution lies in

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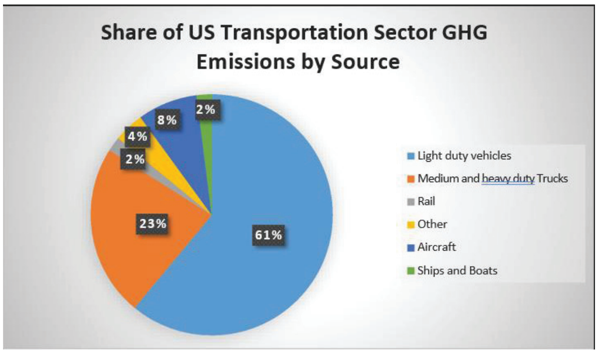

Figure 1: Distribution of greenhouse gas emissions according to EPA report (2015).

implementing strategies targeting them rather than the more numerous but less impactful passenger vehicles.

However, challenges arise when implementing freight truck strategies. The most critical issue is the resistance of governing bodies to adopt changes without assurance that the benefits outweigh the costs. Additionally, most previously implemented strategies, which are further discussed in the Literature Review section, have yielded only minor improvements, discouraging both implementation and future research . Lastly, data on the effects of proposed strategies typically comes from simulations, as gathering practical data would be prohibitively expensive and complex.

The goal of the research reported in this paper was twofold: to test the efficacy and sustainability of a new strategy through modeling and to present the results in terms that clearly demonstrate both the quantitative and qualitative advantages the strategy offers. The chosen strategy combines elements of two previously implemented approaches: exclusive truck lanes and truck platooning.

Exclusive truck lanes, as the name suggests, are lanes restricted to trucks, preventing passenger vehicles from entering. This strategy aims to reduce congestion by minimizing interactions between trucks and passenger vehicles. Truck platooning, on the other hand, involves groups of trucks traveling together at synchronized speeds and spacing from one another using technology. This strategy seeks to reduce congestion by increasing overall speed while improving fuel efficiency.

The proposed strategy, developed by co-author A. Mohamed as part of their doctoral thesis, is the Exclusive Truck Platoon Lane (ETPL) strategy. This approach combines the strengths of exclusive truck lanes and truck platooning to achieve higher flow rates and reduced congestion. In addition to modeling and testing this strategy, the thesis sought to detail all relevant advantages the approach offers.

This manuscript is written to detail and discuss these results. The literature and prior research studied before will be detailed (Section 2), before detailing the modeling process (Section 3), followed by reporting all the relevant results (Section 4). The paper will then conclude by discussing any potential weaknesses (Section 5), followed by the conclusion reached by the research (Section 6).

Literature review

To begin, research into the desired impacts on traffic operations was conducted. With assistance from two reports from the USDOT—The Valuation of Travel Time in Economic Analysis (1997) and Measuring the Impacts of Freight Transportation Improvement on the Economy and Competitiveness [1]—the two main aspects considered were travel time and vehicle operating costs, as both were directly correlated with congestion levels. As congestion increases, travel time and operating costs rise accordingly. A report by Texas A&M's Transportation Institute (TTI) directly calculated the value of time, determining that one hour of delay costs $17.69 for passenger vehicles and $94 for freight trucks.

Additionally, research was conducted on calculating vehicle emissions. The EPA released a fact sheet (2015) designed for this purpose, detailing a six-step process for emissions calculation. This process involves calculating the total gallons of fuel burned, the amount of each type of greenhouse gas released per gallon, the total miles driven, and the percentage of trucks in the traffic mix. However, it was noted that this report only addressed the total number and distribution of vehicles and did not account for road geometry, traffic profiles, or driver behavior.

As a result, alternative methods for calculating emissions were explored. Abou-Senna and Radwan [2] developed the Microscopic Transportation Emissions Model (Micro-TEM), which integrates the Verkehr In Städten Simulation (VISSIM) traffic simulation model and the EPA's Motor Vehicle Emissions Simulator (MOVES) model. This integration enables the model to calculate both microscopic-level traffic characteristics (such as car-to-car interactions and driver behavior) and overall system emissions.

Studies on the effects of driving style on fuel consumption were also reviewed. Research by Michelle [3], Seth (2012), Gonder (2012), and Franke, et al. (2013) demonstrated that driving style significantly impacts fuel consumption. Professional driving habits—such as minimizing stops and maintaining consistent acceleration—led to reduced fuel consumption. Based on these findings, it was hypothesized that implementing intelligent systems capable of autonomous driving could exponentially decrease fuel consumption and associated emissions.

With the analysis parameters established, the research focused on previous studies of freight truck management policies and technology. The first strategy examined was truck-restricted lanes, which prohibit trucks from using specific lanes. Studies by Mwakalonge, et al. [4], Moses [5], Siuhi (2013), and Al Eiseaeia, et al. (2017) indicated that this approach reduced congestion due to fewer lane changes, though the improvements were negligible outside high-traffic scenarios.

Next, the strategy of exclusive truck lanes was analyzed. Numerous studies, including those by Mason et al. (1986), Janson, et al. (1991), and Abdelgawad, et al. (2011), found that

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exclusive truck lanes improved both travel time and speed but only in cases with high truck volumes (with Janson et al. specifically citing a threshold of 30% trucks in the traffic mix).

With one aspect of the ETPL strategy researched, attention turned to platooning technology. While cruise control is commonly used to maintain speed regardless of grade or road type, it is insufficient for maintaining vehicle convoys. To address this, Adaptive Cruise Control (ACC) was developed, allowing vehicles to regulate both speed and the distance to the car ahead. Studies by Davis (2004) and Treiber, et al. (2002) demonstrated positive results, including reduced congestion and improved traffic flow.

However, ACC alone proved inadequate for convoy maintenance, leading to the consideration of Cooperative Adaptive Cruise Control (CACC). CACC enhances ACC by enabling communication among platoon vehicles, allowing the lead vehicle to warn followers of abnormal conditions, such as sharp turns or uneven grades. Additionally, this technology provides environmental benefits: controlled speeds reduce sudden stops, and the close spacing between vehicles decreases drag forces, thereby improving overall fuel efficiency.

More recent advancements in connected and autonomous vehicle technologies continue to strengthen the case for ETPL implementation. Ammourah and Talebpour [6] proposed a Deep Reinforcement Learning approach to support automated vehicle lane-changing decisions, which can complement ETPL frameworks by improving safety and efficiency in mixed traffic scenarios. Furthermore, Hou, et al. [7] explored the challenges and advances in scheduling and planning techniques for large-scale vehicle platooning, emphasizing the importance of coordinated strategies for system-level efficiency. A recent study titled *Enhancing Mixed Traffic Flow with Platoon Control and Lane Management for Connected and Autonomous Vehicles* by Peng Y, et al. [8] provided additional evidence on how intelligent lane management and platooning strategies improve overall highway performance under mixed traffic conditions [9-15].

Methodology

This study employs a three-step methodology to evaluate the impacts of dedicating an existing lane as an Exclusive Truck Platooning Lane (ETPL). The rightmost lane was designated exclusively for trucks to assess improvements in transportation performance and sustainability [16-25].

The analysis followed a structured, three-step methodology to assess the impacts of an Exclusive Truck Platooning Lane (ETPL). The first step involves conducting a traffic operations analysis using the VISSIM simulation model. This analysis evaluates traffic performance on a 10-mile stretch of a limited-access roadway, providing insights into the potential operational benefits and localized effects of implementing an ETPL. In the Second step, emissions were analyzed through the application of the MOVES model to quantify greenhouse gas (GHG) reductions and fuel savings within the test bed. Finally, the results were extrapolated to a state-level assessment using GIS-based spatial analysis, facilitating the development of a policy framework and providing a visual representation of the broader impacts of ETPL implementation across Florida's highway network.

The model corridor

The first step of this study involved selecting a corridor deemed suitable for an Exclusive Truck Platooning Lane (ETPL) analysis. The test bed consisted of a 10-mile segment of Interstate 75 (I-75), simulated as a three-lane limited-access freeway . This corridor was chosen due to its role as a major route connecting Florida's key cities and linking the state to other U.S. states, such as Georgia. It also features high annual average daily traffic (AADT) [26-35], a substantial percentage of truck traffic, and access to reliable traffic and geometric data. These factors ensured that the selected corridor not only accommodated significant truck traffic but also provided a realistic representation of conditions where ETPL implementation could deliver measurable benefits.

To thoroughly evaluate the potential benefits of ETPL implementation, four simulation scenarios were developed:

1. **2016 base-case scenario (Without ETPL)**: This scenario represented the existing traffic conditions and served as the baseline for assessing current performance metrics.

2. **2035 base-case scenario (Without ETPL)**: This scenario projected future traffic conditions without ETPL, offering insights into the anticipated challenges and performance limitations under increased traffic demand.

3. **2016 ETPL scenario**: This scenario analyzed the immediate benefits of dedicating the existing rightmost lane as an Exclusive Truck Platooning Lane (ETPL), highlighting short-term improvements in traffic flow and sustainability.

4. **2035 ETPL scenario**: This scenario assessed the long-term benefits of converting the rightmost lane into an ETPL under projected future traffic conditions, evaluating its scalability and sustained effectiveness.

The simulation scenarios were systematically designed to account for variations in peak hour volumes, truck percentages, speeds, and roadway grades along the corridor. In scenarios with ETPL, the rightmost lane was designated exclusively for trucks, with platoons modeled as five-vehicle convoys maintaining 40-foot headways. Passenger vehicles were restricted from entering the ETPL, allowing for a focused analysis of truck-only operations. The roadway characteristics and variables used in the model are Presented in Table 1.

Development of the VISSIM model

Due to the limited availability of corridors with dedicated truck lanes in the United States and the emerging nature of truck platooning technology, advanced simulation tools were required to assess the feasibility and potential impacts of implementing an Exclusive Truck Platooning Lane (ETPL). For

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Table 1: Base roadway characteristics/variables for each time period.

Year	2016	2035
Number of Lanes	3	3
Capacity (veh/hr/lane)	1,500	1,500
Free-Flow Speed (mph)	70	70
Annual Average Daily Traffic (veh/day)	65,500	100,500
Truck Percentage	20%	20%
Truck Volume (trucks/day)	13,100	20,100

this study, the VISSIM microscopic traffic simulation model was employed to develop a calibrated and validated test bed [36-40]. The existing roadway network was replicated within the VISSIM environment and rigorously calibrated to accurately represent real-world traffic patterns with accuracy.

The calibration process began with a series of simulation runs using VISSIM's default parameters while varying the seed numbers. The seed number serves as the initial input for the random number generator, which influences various stochastic elements of the simulation. After each run, the simulated traffic volumes on selected corridors were compared to corresponding field observations. The accuracy of the simulation was assessed by calculating the relative error between simulated and actual volumes. If the relative error for any link exceeded a 10% threshold, traffic volumes were adjusted accordingly—either increased or decreased—based on the direction and magnitude of the error.

Key simulation elements such as car-following behavior, lane-changing maneuvers, and driver characteristics are influenced by random variation. As different seed values can lead to varying outcomes even within the same network, multiple runs were performed using different seeds. Through iterative refinements and repeated simulations, the seed values that yielded results within the 10% relative error range were selected as the best match to actual traffic conditions.

MOVES model development

The primary objective of this section is to assess the impact of dedicating the existing rightmost lane as an Exclusive Truck Platooning Lane (ETPL) on vehicle emissions along limited-access highways. The analysis employed the MOVES emissions model to evaluate both the base-case and ETPL scenarios [40-50], quantifying the changes in emission rates. The focus was on understanding the influence of truck platooning on emissions along the selected corridor.

The MOVES model calculates emissions based on vehicle operating modes, enabling an analysis of various driving behaviors such as cruising, deceleration, and average speed. Traffic conditions for each scenario were simulated using VISSIM microsimulation software, which produces FZP files. These files provide second-by-second records of vehicle behavior, including vehicle type, location, and speed, which are crucial inputs for emissions estimation across different vehicle categories.

To determine the operating mode distribution for the test corridor, Vehicle Specific Power (VSP) values were calculated for passenger vehicles, while Scaled Tractive Power (STP) values were calculated for heavy-duty vehicles. These values were derived using Equations "(1)" and "(2)" , providing a detailed representation of the energy requirements and operating modes of vehicles within the corridor. This approach ensured a robust and detailed estimation of emissions under varying traffic and operational conditions.

$$VSP = \frac{AV + BV^2 + CV^3}{M} + Va \quad (1)$$

$$STP = \frac{AV}{f_{scale}} + \frac{BV^2}{f_{scale}} + \frac{CV^3}{f_{scale}} + Va \quad (2)$$

Where M weight (metric tons), A the rolling resistance A (kw-sec/m), B the rotating term B (kw-sec2/m2), C the aerodynamic drag (kw-sec3/m3), v the vehicle velocity (m/s), a the acceleration (m/s2), and f scaling factor.

It should be noted that the VISSIM FZP files contain extensive data, including vehicle speed recorded for each second of the simulation. A Visual Basic script was created to efficiently process this data for integration with the MOVES model, a Visual Basic Script was developed [51-60]. This script automated the conversion of FZP file data into operating modes compatible with the MOVES framework.

The script calculated VSP and STP values for each vehicle and categorized them into specific "bins" as defined by the MOVES classification system. These bins, based on speed and power characteristics, ensured an accurate representation of vehicle operating modes within the MOVES model, facilitating precise emissions estimation. The classification bins utilized in this study are detailed in Table 2.

State level policy

After evaluating the test bed corridor, a statistical model was developed to help decision-makers assess the potential of dedicating the existing rightmost lane an Exclusive Truck Platooning Lane (ETPL) within Florida's highway system. This state-level assessment tool predicts travel time and

Table 2: Operating Modes for Running Emissions.

<table>
<tr><th rowspan="2">VSP class (KW/ton)</th><th colspan="3">Speed class (mph)</th></tr>
<tr><th>1-25</th><th>25-50</th><th>> 50</th></tr>
<tr><td>>30</td><td rowspan="7">Bin 16</td><td rowspan="2">Bin 30</td><td rowspan="2">Bin 40</td></tr>
<tr><td>27-30</td></tr>
<tr><td>24-27</td><td>Bin 29</td><td>Bin 39</td></tr>
<tr><td>21-24</td><td rowspan="3">Bin 28</td><td rowspan="2">Bin 38</td></tr>
<tr><td>18-21</td></tr>
<tr><td>15-18</td><td rowspan="2">Bin 37</td></tr>
<tr><td>12-15</td><td>Bin 27</td></tr>
<tr><td>9-12</td><td>Bin 15</td><td>Bin 25</td><td rowspan="2">Bin 35</td></tr>
<tr><td>6-9</td><td>Bin 14</td><td>Bin 24</td></tr>
<tr><td>3-6</td><td>Bin 13</td><td>Bin 23</td><td rowspan="3">Bin 33</td></tr>
<tr><td>0-3</td><td>Bin 12</td><td>Bin 22</td></tr>
<tr><td><0</td><td>Bin 11</td><td>Bin 21</td></tr>
</table>

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emissions impacts by integrating Generalized Linear Modeling (GLM) with Geographical Information System (GIS) tools for quantitative analysis and spatial visualization.

The GLM estimated travel time and emissions savings from ETPL implementation by incorporating key variables such as peak hour volumes, truck percentages, speeds, roadway grades, and the number of lanes. By comparing base-case and ETPL scenarios, the model provided a robust framework for evaluating impacts under diverse traffic conditions.

The results were integrated into GIS to spatially represent ETPL impacts across Florida's highway network. Traffic data from INRIX and the Florida Department of Transportation (FDOT) were used to generate heat maps through kernel density analysis, visualizing travel time differences and identifying potential ETPL corridors. The GIS tool proved highly effective in highlighting critical corridors by assigning colors to indicate performance levels—such as red for significant delays and green for no delays—facilitating the prioritization of areas needing intervention.

Study results

Test bed results

Base-case scenario: In the base-case scenario, vehicles displayed consistent acceleration patterns with minimal lane usage restrictions. Both trucks and passenger vehicles maneuvered freely across all lanes, leading to relatively smooth traffic flow overall. However, trucks experienced higher negative acceleration values, which reduced their speeds and increased travel times compared to other vehicles as shown in Figures 2,3.

Scenario with ETPL: In the second scenario, with the implementation of ETPL, trucks experienced no significant acceleration fluctuations as they traveled smoothly within the dedicated ETPL, free from human reactions and interactions with passenger vehicles as shown in Figure 4. This streamlined operation highlights the benefits of ETPL in reducing variability in truck movement.

Passenger vehicles, on the other hand, showed slightly more deceleration variability as shown in Figure 5. This was primarily due to the reduced maneuvering space caused by the restriction of passenger vehicles from the ETPL. The constrained lane availability resulting in minor deceleration changes due to altered traffic dynamics .

Despite these adjustments, the overall impact on traffic performance was minimal, indicating that the introduction of ETPL did not significantly disrupt passenger vehicle behavior while offering smoother and more efficient travel conditions for trucks.

It is important to note that this implementation is intended only during peak hours, when traffic volumes and potential conflict points between vehicle types are at their highest. By restricting passenger vehicles from entering the existing furthermost lane during these hours, the likelihood of crash

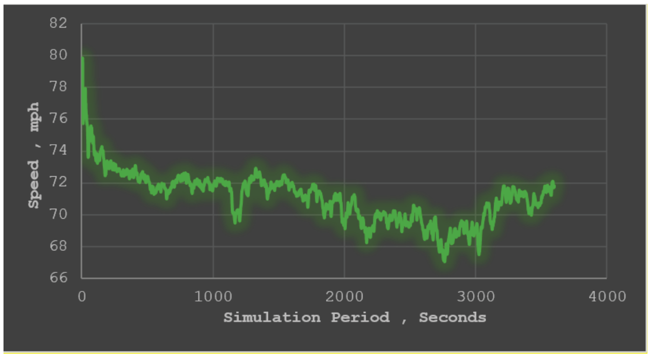

Figure 2: Speed distribution of passenger vehicles in "base-case".

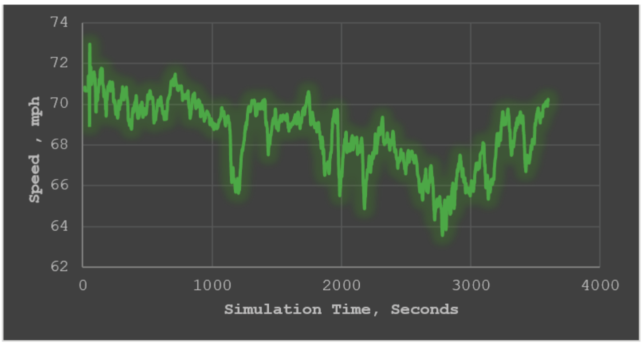

Figure 3: Speed distribution of Trucks in "base-case".

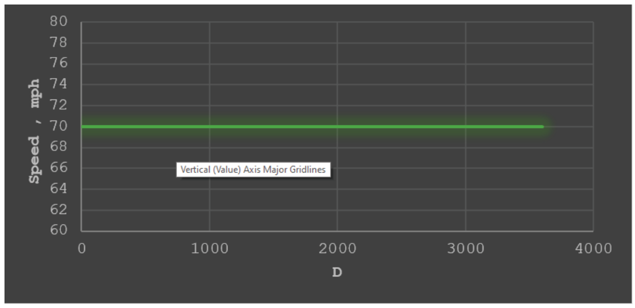

Figure 4: Acceleration distribution of Trucks in in ETPL scenario.

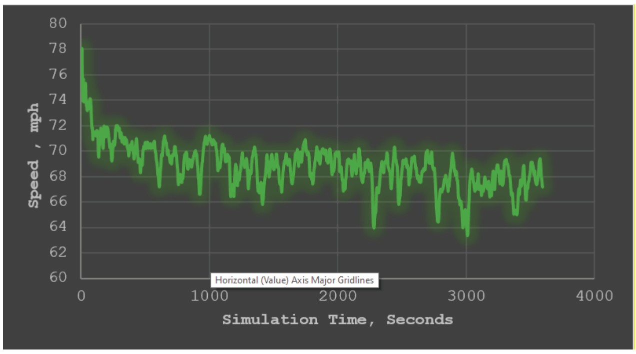

Figure 5: Acceleration distribution of passenger vehicles in ETPL scenario.

points between passenger vehicles and trucks is expected to decrease significantly. This targeted application of ETPL not only preserves overall traffic flow but also contributes to enhanced safety outcomes by minimizing interaction zones between the two vehicle classes.

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Monetary value impacts

➢ **Monetary value of delay**

The results indicate that truck travel time under the platooning lane policy is significantly lower compared to the base scenario as shown in Table 3. This difference becomes more pronounced in 2035 as shown in Table 4, attributed to the increase in annual average daily traffic (AADT) from 65,500 to 100,500. Additionally, passenger vehicle travel time increased marginally by only 0.8% with the implementation of the platooning lane, while truck travel time decreased by 18% in 2016 and 24% in 2035.

Monetary savings were calculated using time value costs from the 2015 Urban Mobility Scorecard report, which estimates the value of travel time delay at $17.67 per hour for passenger vehicles and $94.04 per hour for trucks in 2016. The results, illustrated in Figure 6, demonstrate substantial monetary savings achieved through ETPL implementation, with greater savings projected for 2035 due to higher traffic volumes.

➢ **The monetary value of emissions**

MOVES was utilized to calculate the emissions according to each operating mode cycle. The results of simulations results are shown in Figure 6. The results, visualized in Figure 7, show a reduction in yearly CO2 emissions for the ETPL scenario compared to the base scenario in both 2016 and 2035. Specifically, the ETPL scenario reduces CO2 emissions more significantly in 2035, correlating with the increase in traffic volumes and operational efficiency improvements.

As illustrated in Figure 8, fuel consumption data reveal reductions in both diesel and gasoline usage under the ETPL scenario. This decrease reflects improved traffic flow and reduced idling times for trucks using the platooning lane. The trend is more pronounced in 2035 due to higher traffic volumes and the corresponding impact of ETPL in optimizing traffic patterns.

The associated fuel cost savings, shown in Figure 9, further emphasize the economic benefits of ETPL implementation. Annual fuel costs are significantly lower for the ETPL scenario compared to the base case, with greater savings projected for 2035 due to increased reliance on heavy-duty vehicles and fuel

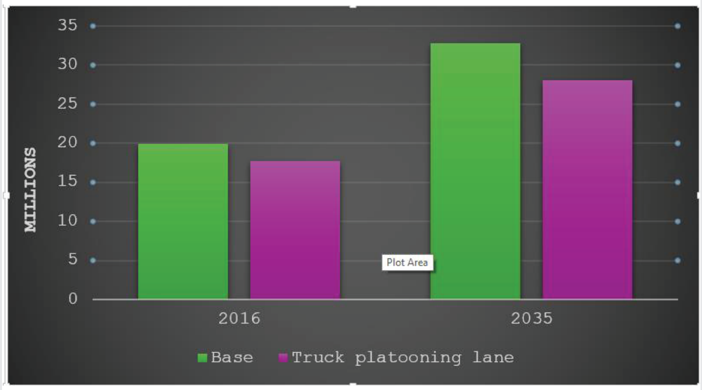

Figure 6: Travel Time Cost for Each Scenario.

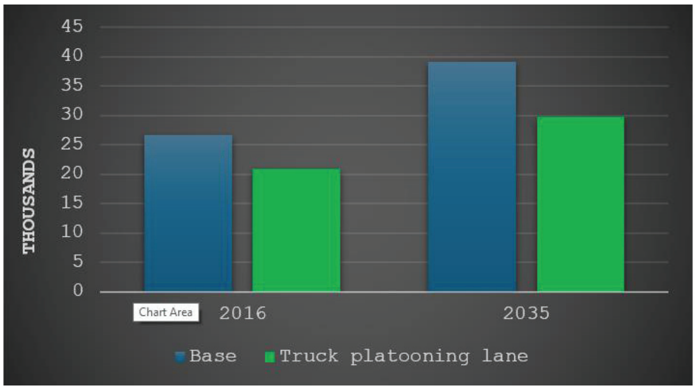

Figure 7: Emissions CO2 Yearly (kg).

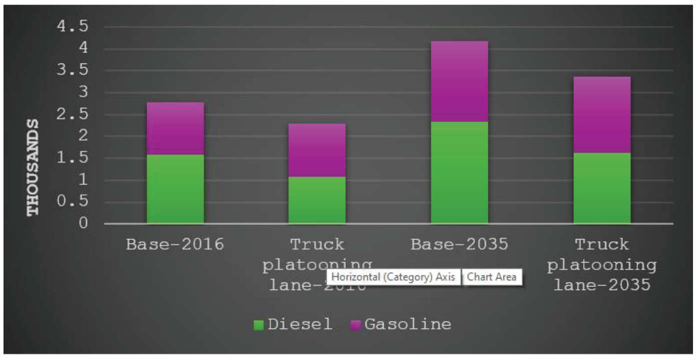

Figure 8: Fuel Consumption (Gallons).

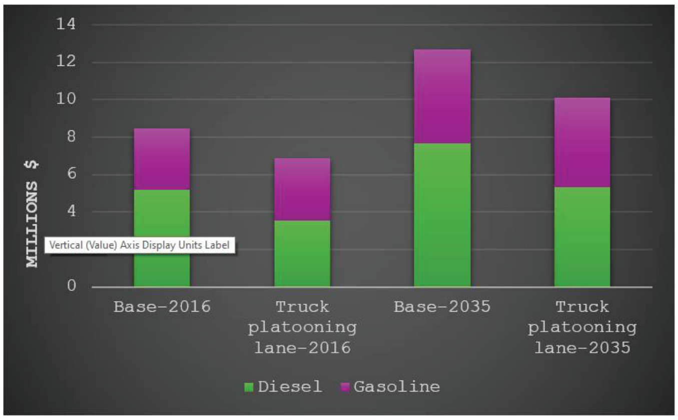

Figure 9: Annual Fuel Consumption Cost for Each Scenario.

Table 3: Scenarios Results for 2016 Traffic Data.

	Base Scenario	Truck Platooning Lane Policy	Time Saved (hrs.)
Light-Duty Vehicles Travel Time (hrs.)	453 hours	456.8 hours	-3.8
Trucks Travel Time (hrs.)	107 hours	87 hours	20

Table 4: Scenarios Results for 2035 Traffic Data.

	Base Scenario	Truck Platooning Lane Policy	Time Saved (hrs.)
Light-Duty Vehicles Travel Time (hrs.)	688 hours	691 hours	-3
Trucks Travel Time (hrs.)	188 hours	143 hours	45

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consumption efficiency. These findings not only demonstrate the monetary benefits. They also underline the environmental advantages, including reduced emissions and decreased fuel usage , reinforcing the case for implementing ETPL on high-traffic corridors.

State level policy

To develop a state-level policy, thousands of simulation runs would typically be required to cover the range of variables such as traffic volume, truck percentages, and the number of lanes. This process would consume substantial resources and time. To address this, a custom D-Optimality experimental design was employed, reducing the required experimental runs to just 70 while still capturing main effects and two-way factor interactions. This approach ensured precise, cost-effective modeling and applicability across a broad range of traffic conditions. The optimal design process led to 70 simulation runs. The predictive model is calibrated by considering all main effects and their 2-way factor interaction (Table 5).

Table 5: Factors and levels ranges.

Volume	1,000-10,000 (vph)
Speed	20-70 (mph)
Truck %	0%-28%
No of Lanes	3,4 and 5

In order to demonstrate the implication of the estimated model we apply the developed model to the state corridors. A data mining process was performed by employing GIS techniques. SIS corridor traffic parameters were obtained from several sources such as INRIX, FDOT traffic shapefiles database. INRIX is a company which provides historical and real time traffic information. SIS corridor volumes are obtained by converting the historical Annual Average Daily Traffic (AADT) in 2016 provided by FDOT. Number of lanes and truck percentages are also found in FDOT database whereas monthly average speeds are aggregated from INRIX's 15-minute average speed data (June 2016). Final dataset was prepared by merging geo-coded datasets on a GIS platform. GLM estimation results were employed to the GIS dataset to predict travel time and densities on SIS corridors. Furthermore, travel time prediction results of ETPL scenarios were subtracted from base scenarios results and travel time differences were monetized by using TTI monetary values of vehicle types. To that extent, travel time cost/benefit of applying ETPL policies at each SIS corridor section was generated.

For illustration purposes, a spatial representation is presented (Figure 10) by plotting the cost (hot spots) / benefit (cold spots) of ETPL application in a kernel density heat map. The heat map color bar shown in the legend denotes the annual value of travel time impacts per mile ranging from blue (i.e. positive impact, benefit) to red (negative impact).

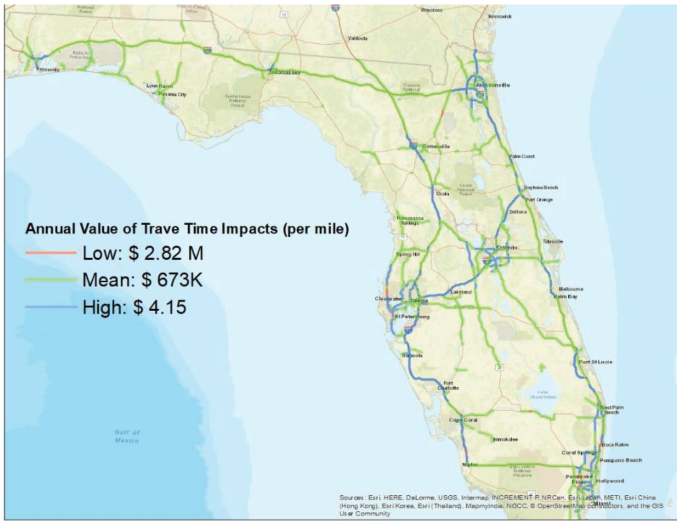

Figure 10: Annul Value of Travel Time Saving on SIS Corridors after ETPL Policy.

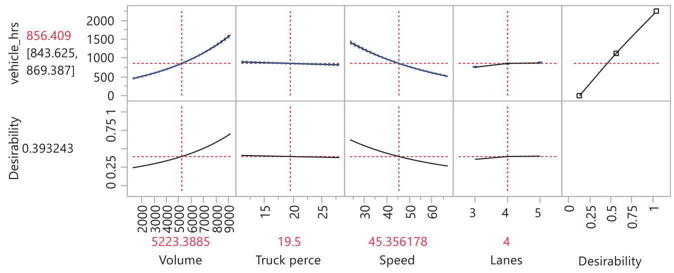

Figure 11a: Desirability profiles for ETPL implemented passenger vehicles.

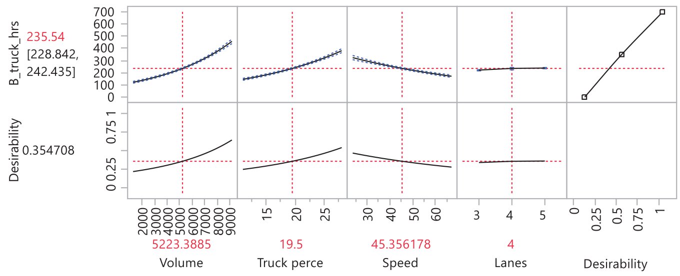

Figure 11b: Desirability profiles for ETPL implemented for Trucks hours.

Travel time state policy

GLM predictions were calculated for both the base and after dedicating the existing rightmost lane (ETPL) scenarios for passenger vehicles and trucks. For illustrative purposes, Figure 11a highlights passenger vehicle travel time predictions across varying levels of dependent variables, while truck travel time changes under the ETPL scenario are shown in Figure 11b.

Differences in travel times between these scenarios for each vehicle type were monetized using TTI monetary values, enabling the calculation of cost-benefit impacts of ETPL policies for each SIS corridor section as shown in Figure 10. Results show the majority of time savings occur in major cities and along the primary interstate corridors, such as I-75 and I-95 (Table 6).

Emissions state level policy

This section evaluates the impact of dedicating the existing rightmost lane an Exclusive Truck Platooning Lane (ETPL) on

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Table 6: Travel Time Prediction Model Statistics Parameters for GIS Maps.

Variable Names	Base Scenario				ETPL Scenario			
	Vehicle Hours		Truck Hours		Vehicle Hours		Truck Hours	
	Estimate Value	χ2	Estimate Value	χ2	Estimate Value	χ2	Estimate Value	χ2
Intercept	6.73	152609	5.4	30666.2	6.63	133259	4.7	13840.2
Speed (24 mph to 67 mph)	-0.49	1693.4	-0.41	353.07	-1.145	1890.03	-	-
Volume (1273 veh/h to 9174 veh/h)	0.44	1148.6	0.4	252.52	0.907	550.99	0.3	84.7
Truck Percentage (11% to 28%)	-0.15	142.98	0.4	260.15	-0.05	11.57	0.4	551.6
Lanes [4-3]	0.08	46.94	0.06	7.82	0.12	118.01	0.1	11.5
Lanes [5-4]	0.01	0.76	0.01	0.32	0.01	1.86	0.1	7.4
Volume*Speed	0.14	95.54	0.12	18.59	0.10	40.04	-	-
Truck Percentage *Lanes[4-3]	0.08	24.52	0.08	6.04	0.00	0.01	-	-
Truck Percentage *Lanes[5-4]	-0.03	3.75	-0.02	0.22	-0.12	47.74	-	-
Speed*Lanes[4-3]	0.08	23.60	0.09	8.59	0.03	3.02	-	-
Speed*Lanes[5-4]	-0.05	8.95	-0.03	0.67	-0.04	6.88	-	-
Volume*Lanes[4-3]	0.22	162.9	0.26	61.31	0.31	292.26	0.2	12.2
Volume*Lanes[5-4]	0.24	182.2	0.19	31.93	0.21	139.72	0.3	39.1
Speed*Truck Percentage *Lanes[4-3]	-0.11	20.02	-0.07	2.45	-0.17	49.74	-	-
Speed*Truck Percentage *Lanes[5-4]	0.08	4.91	-0.05	0.55	0.14	14.90	-	-
Volume*Speed*Truck Percentage	0.24	21.94	-	-	0.18	11.51	-	-
Volume*Speed*Truck Percentage *Lanes[4-3]	0.09	1.47	0.42	21.64	-0.04	0.35	-	-
Volume*Speed*Truck Percentage *Lanes[5-4]	-0.50	45.10	-0.60	17.24	-0.35	21.54	-	
Summary Statistics								
Log-Likelihood	7088.21		2476.92		7193.48		794.81	
Akaike Information Criteria	2495.86		1192.61		1588.30		604.57	
LR chi square (Number of Predictors)	14176.43 (17)		4953.85 (16)		14386.96 (17)		4953.85 (6)	

fuel consumption and greenhouse gas (GHG) emissions through 140 simulations—70 for the base scenario and 70 for the ETPL scenario—based on the D-Optimal design recommendations. Emissions were predicted for Strategic Intermodal System (SIS) segments in Florida using a Generalized Linear Modeling (GLM) methodology combined with the MOVES model.

Platooning trucks were tested at two speeds (55 mph and 70 mph), with MOVES estimating emissions based on variables such as vehicle types, fuel types, traffic conditions, and driving behaviors. VISSIM supplied second-by-second vehicle data to replicate real-world driving conditions, facilitating precise emission calculations for various vehicle categories.

The results showed that the ETPL scenario significantly reduced fuel consumption and GHG emissions compared to the base scenario, highlighting the environmental benefits of implementing truck platooning lanes (Figures 12-17).

Trucks in the base scenario consume more fuel due to frequent deceleration, braking, and unstable traffic flow caused by congestion and limited maneuverability. In contrast, the ETPL scenario stabilizes traffic flow, allowing trucks to maintain consistent speeds and reduce braking and acceleration events. This leads to lower fuel consumption and emissions, especially under high truck percentages and traffic volumes. Furthermore, reduced aerodynamic drag in the ETPL scenario contributes to fuel efficiency and emissions reduction. Overall, implementing ETPL policies significantly decreases truck emissions by minimizing braking, idling, and acceleration rates.

The 55 mph ETPL scenario resulted in the lowest annual

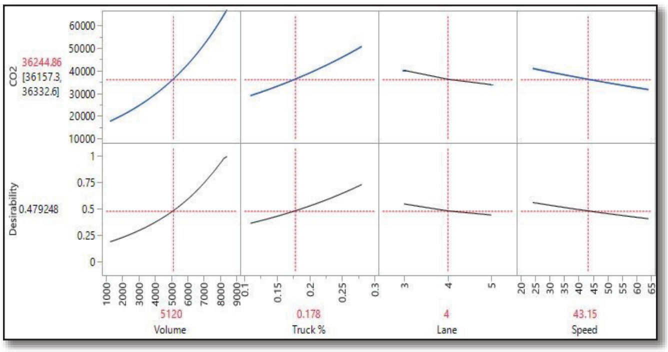

Figure 12: CO_2 emissions (kg) Prediction profiles for Base Scenario.

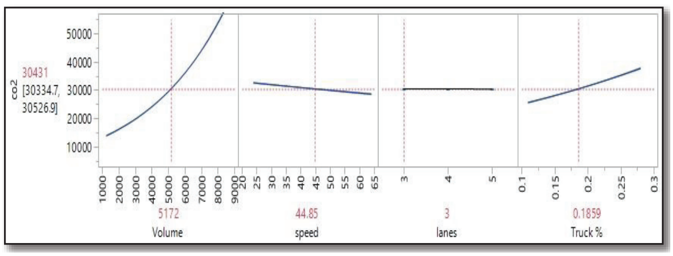

Figure 13: CO_2 Emissions (Kg) Prediction Profiles for ETPL Emissions 70 Mph.

emissions, with an annual emission total of 96,711 kg, compared to 369,429 kg of the 70 mph ETPL implementation and the 594, 539 kg of the "base-case" scenario. This reduction is attributed to lower Scaled Tractive Power (STP) at 55 mph than those traveling at 70 mph, resulting in a lower emissions rate. These findings highlight the environmental benefits of maintaining optimal speed limits in ETPL operations.

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Discussion

The results are clear, in that the model showed that dedicating the existing rightmost lane as ETPL lanes would serve as a direct benefit to both traffic operation and environmental impact. The reduction in truck travel time is significant compared to the small increase in passenger car travel time, which, due to the truck's higher delay value cost and fuel demand, justifies the trade-off. This value is expected to rise. As vehicle volumes increase , which is a near-certainty as freight and transport rise to meet population growth. In addition, the lower emission rates due to the platoons completely minimizing any drag force and intermittent stops lead to increased fuel efficiency.

However, it is essential to recognize that these results are derived from simulation models rather than real-world data. While VISSIM and similar tools are designed to account for various variables and scenarios, they inherently have limitations. Some aspects of the ETPL strategy may have been overlooked in the model design, leading to potential discrepancies during real-world implementation. Although the model uses accurate data , its results should be interpreted as indicative rather than definitive.

Another critical consideration is the cost and logistics of implementing ETPL strategies. For the system to function effectively, all trucks must be equipped with Cooperative Adaptive Cruise Control (CACC) technology. This requirement

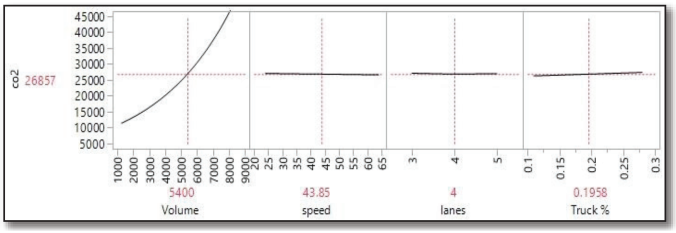

Figure 14: CO_2 Emissions (Kg) Prediction Profiles for ETPL Emissions 50 mph.

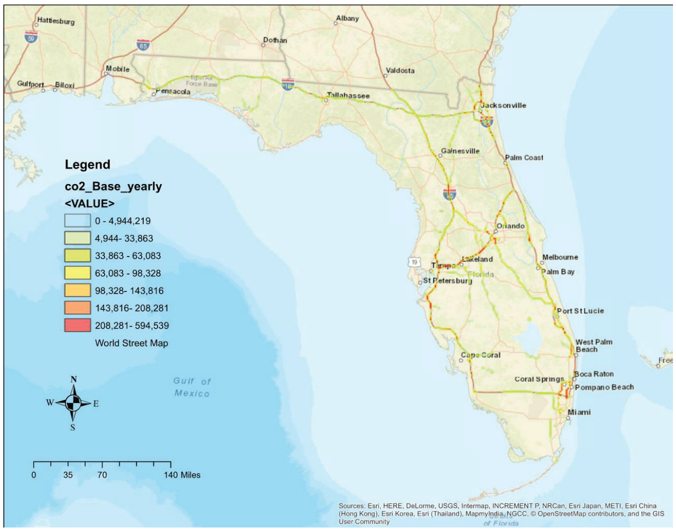

Figure 15: Emissions heat map of "base-case" scenario.

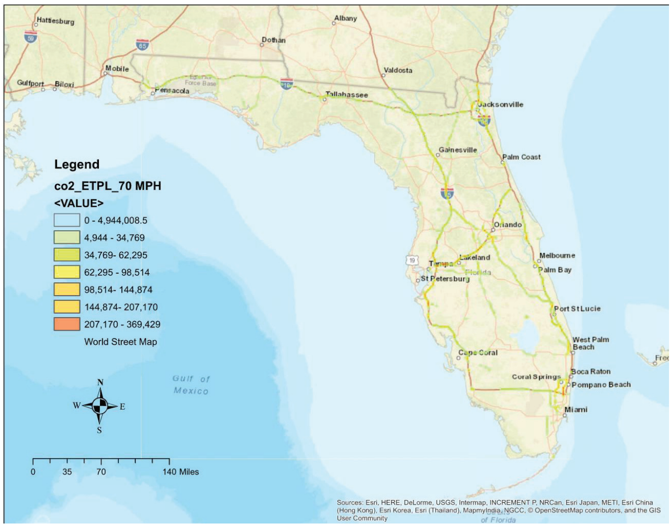

Figure 16: Emissions heat map of ETPL implementation scenario (70 mph).

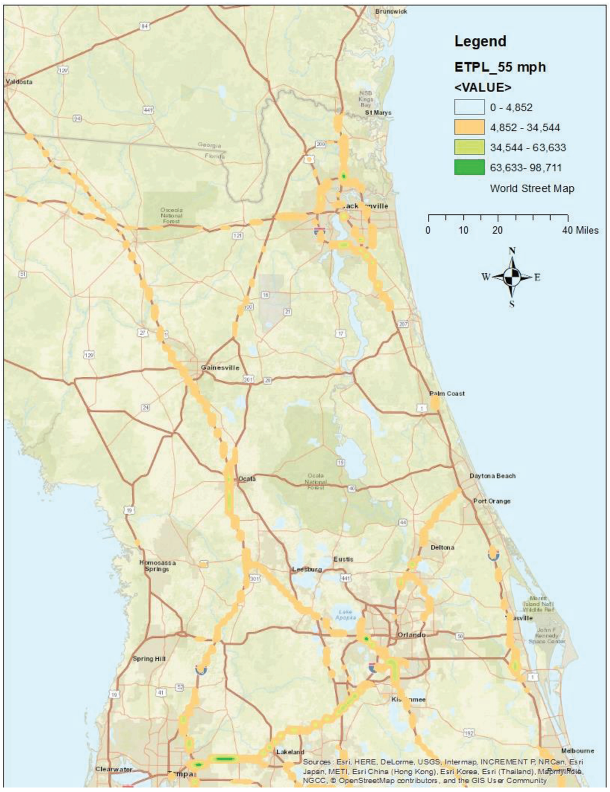

Figure 17: Emissions heat map of ETPL implementation scenario (55 mph).

imposes substantial costs on vehicle owners and raises compatibility concerns if different manufacturers produce systems from different manufacturers may lack interoperability.

Enforcement of ETPL lane exclusivity also presents practical challenges. Enforcing ETPL restrictions may be challenging, as continuous monitoring is impractical , nor is it cost-effective to install cameras for monitoring violations. Additional questions arise regarding whether passenger vehicles should face penalties for using an empty ETPL lane. This consideration applies specifically when they do not interfere with truck operations. Moreover, the configuration of U.S. highways,

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where the right lane often serves as an exit lane, complicates ETPL exclusivity. Passenger vehicles may need to enter the ETPL to access their destinations, which may undermine the exclusivity and intended benefits of ETPL.

To address these challenges, alternative exit designs or dedicated bypasses for passenger vehicles should be investigated. However, this study focuses on the operational and environmental impacts of ETPL implementation rather than on the construction or redesign of infrastructure. Future research should explore feasible solutions for accommodating these interactions while preserving ETPL lane performance and safety.

Additionally, it is worth noting that this implementation is proposed only during peak hours, when traffic congestion and the risk of conflicts between passenger vehicles and trucks are highest. Restricting passenger vehicles from the existing rightmost lane during these hours effectively reduces crash points and improves safety. The separation of vehicle types also opens the possibility of increasing the posted speed limit for ETPL, further reducing truck travel time and improving freight efficiency. Although passenger vehicles may face marginally increased deceleration due to reduced lane availability, with negligible overall effects on traffic performance.

In summary, ETPL provides smoother truck operations, reduced travel times, improved fuel efficiency, and lower emissions—especially as platooning eliminates drag forces and intermittent braking. These operational and environmental benefits will likely become more significant as traffic volumes grow, reinforcing the value of implementing ETPL in the future.

While the benefits of ETPL implementation are clear, logistical, technological, enforcement, and logistical challenges must be addressed to ensure its successful real-world adoption. Further studies should address these barriers and enhance ETPL strategies for practical implementation for practical application.

Conclusion

The Exclusive Truck Platooning Lane (ETPL) strategy offers substantial benefits for the efficiency and sustainability of traffic systems. By providing dedicated freight lanes, the ETPL strategy reduces interactions between slower trucks and faster passenger vehicles, thereby reducing conflicts that can lead to collisions and lower Levels of Service (LOS) for passenger traffic . This exclusivity while causing only a marginal increase in passenger car travel time . The elevated cost of truck delays is fully compensated by time savings and efficiency gains by these improvements, enhancing overall system efficiency.

Additionally, ETPL implementation contributes to reduced greenhouse gas emissions by minimizing the effects of friction, drag force, and rolling resistance. The environmental benefits are further amplified when trucks travel at lower speeds, as the reduction in travel time offsets the slightly longer travel time at reduced speeds .

ETPL serves as a hybrid strategy integrating traffic management and environmental sustainability approaches. Its potential for improvement is significant, especially when combined with emerging technologies and strategies. However, realizing its full potential requires further research. Detailed modeling and real-world trials are also needed , and real-world studies. Simulation tools such as VISSIM, as utilized in this study, offer a robust foundation for understanding ETPL's impacts, but further research is needed to validate and scale this promising solution.

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