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Abstract

Freight traffic on the B1 corridor between Wels and Marchtrenk in Upper Austria causes congestion, travel time losses and local emissions, especially during peak hours. This paper presents a microscopic traffic simulation of the corridor using SUMO to evaluate two complementary decarbonisation strategies for regional logistics: electrification of a nine-truck fleet and network redesign through the replacement of signalized intersections by roundabouts. Realistic network, fleet, and demand data are used to build a 6.5 km simulation model of the corridor. A baseline scenario with a conventional diesel fleet and the existing signalized intersections is compared against scenarios featuring a mixed diesel-electric fleet and a fully electric fleet powered by photovoltaic (PV) generation at the depot and operating on a roundabout-based intersection layout. The microsimulation results show that the combined electrification and roundabout strategies can increase the number of completed trips, reduce average travel times and significantly lower CO_2 emissions along the corridor. These findings illustrate the potential of coupling fleet electrification with targeted infrastructure modifications to improve both efficiency and sustainability on regional freight corridors.

1. Introduction

Urban and industrial transport corridors are increasingly affected by congestion, inefficiencies, and environmental burdens caused by high freight traffic volumes. In Europe, and particularly in industrial regions such as Upper Austria, these challenges are amplified by the concentration of logistics and manufacturing centers along key road networks. Efficient and sustainable traffic management therefore represents a critical component for regional economic performance and environmental protection.

The corridor between the cities of Wels and Marchtrenk in Upper Austria has become one of the most important freight and logistics routes in the region. It connects major distribution centers, such as the SPAR central logistics hub in Wels and the TGW industrial area in Marchtrenk, with surrounding transport infrastructure including Linz–Hörsching Airport. However, the B1 federal highway (Linzer–Welser Straße) frequently experiences congestion, especially during peak hours, due to the high share of heavy-duty vehicles—approximately 10% of total traffic flow [1]. This congestion leads to extended travel times, reduced logistic reliability, and increased pollutant emissions.

Previous studies have shown that freight transport is a major source of CO_2 and particulate matter (PM_{10}) emissions in urban areas, particularly under stop-and-go conditions. Local air quality measurements confirm that intersections along Linzer Straße record the highest pollutant concentrations in Wels. As the industrial zone continues to expand, sustainable transport strategies are required to mitigate the growing environmental impact while maintaining efficient logistics operations.

Traffic microsimulation models, such as the Simulation of Urban Mobility (SUMO), enable researchers to evaluate potential interventions—like alternative vehicle technologies or intelligent signal control—under

realistic but controlled conditions. These models can simulate thousands of vehicles, intersection behaviors, and emission profiles to identify solutions that optimize both mobility and sustainability outcomes.

Based on this context, the present study applies a SUMO-based simulation to the Wels–Marchtrenk corridor to explore two complementary strategies for reducing emissions and improving traffic flow. Specifically, the following research questions are addressed:

1. How much are CO_2 emissions reduced if diesel trucks from our fleet are replaced by e-trucks charged with the PV from the depot?

2. How does implementing roundabouts influence the reduction of the operational efficiency of multi-stop freight routes?

To answer these questions, the study simulates both the current diesel-based logistics operations and alternative configurations featuring electric vehicles and roundabouts. The findings are expected to demonstrate how electrification and roundabouts can jointly contribute to reducing emissions and improving transport efficiency in a regional logistics context.

2. Related Work

The use of microscopic traffic simulators like SUMO has expanded over the last decade to support urban planning and the design of mobility solutions. Simulations have been shown to allow safe and cost-effective evaluations of measures that help reduce congestion, improve the efficiency of traffic logistics routes, and reduce emissions, ensuring that solutions are effectively implemented in the real world.

The most relevant measures for this work have already been evaluated in the past, focusing on optimizing traffic management through electrification and roundabouts and priorities, improving urban logistics and infrastructure through simulation, and quantifying the environmental impacts (emissions) resulting from these interventions.

One of the most fruitful lines of research has been the application of SUMO to design intelligent traffic control systems for urban flow. In dense urban environments, real-time synchronization and adaptation roundabouts can dramatically reduce delays. A clear example of success was the study conducted by Kyoungho Ahn, Sangjun Park, and Hesham A. Rakha (2020) used microsimulation to compare the energy consumption of BEVs at roundabouts, signalized intersections, and stop signs. Their work challenged the assumption that regenerative braking fully compensates for stops. The results concluded that, for BEVs, roundabouts are the most efficient traffic control method, significantly outperforming traffic signals. This is because the energy required to accelerate from a complete stop exceeds the energy recovered by regenerative braking (whose efficiency is less than 100%). The energy saving from signal coordination was less significant compared to its impact on internal combustion vehicles. Therefore, maintaining momentum at roundabouts is a superior strategy to the stop-regenerate-accelerate cycle at traffic signals.

Many breakthroughs in traffic light optimization had also been done. Advanced traffic light control algorithms have been implemented in SUMO to minimize congestion at urban intersections. A clear example was tested at a busy intersection in the city of Kilis, Türkiye, where an adaptive traffic light system based on

fuzzy logic was developed. Using real traffic capacity data from that intersection, the researchers compared the performance of the smart traffic light with that of traditional fixed control; the results indicate average wait time reductions of between 50% and 76% with the adaptive system . This represents a substantial improvement in fluidity, achieved only by dynamically readjusting the green times according to the queues detected in each cycle [3].

Recent AI-based approaches have shown promising results in reducing vehicle emissions through intelligent traffic light control. A prominent example is the EcoDriveAI system, which employs deep reinforcement learning combined with cooperative vehicle-to-infrastructure (V2I) communication to control traffic signals in real time. This system was tested in urban simulations using the SUMO platform and proved highly effective in minimizing both delays and pollutant emissions. Specifically, experiments showed a 12%–15% reduction in CO_2 emissions, mainly attributed to fewer unnecessary stops and frequent starts, which optimizes fuel consumption on the simulated network. Furthermore, the system was able to improve travel times for emergency vehicles through coordinated preemption mechanisms, without compromising overall traffic flow [4].

SUMO has also been used specifically to optimize freight transport routes and evaluate infrastructure changes to improve mobility. Mentioned earlier, the article by Validi et al. analyzed cooperative urban delivery strategies in the city of Linz, Austria [5]. A last-mile distribution scenario was simulated, comparing operations with two conventional trucks, each with its own trailer, versus load consolidation in a single high-capacity truck (with a double trailer) covering both deliveries. The results conclude that deliveries in a single heavy-duty vehicle reduced fuel consumption by ~28% and

total CO_2 emissions by 34% compared to the base case. Although this simulation assumes controlled conditions, it suggests that through collaboration between companies (sharing cargo and routes), environmental impacts can be drastically reduced without sacrificing delivery times. In fact, the comparison included the total delivery time, showing that the consolidated route could be completed in a competitive timeframe despite involving a single vehicle serving multiple destinations.

A prominent example of the use of SUMO to assess new road infrastructure is found in the city of Osnabrück, Germany, where researchers developed an urban digital twin of the traffic system using real-world vehicle counting data. The model was calibrated with historical traffic counts at multiple points in the city, allowing congestion patterns to be reproduced with high accuracy by time of day. The PHEMlight module was integrated into this simulated environment to calculate CO_2 and other pollutant emissions under different traffic scenarios. Thanks to this combination, the study clearly identified which areas and time zones generated the highest emission peaks, and specific mitigation measures were proposed, such as temporary access restrictions, dynamic traffic signal synchronization, and changes to the road hierarchy.

In light of the reviewed studies, it is observed that the application of SUMO and simulation techniques has been successful in addressing traffic problems both in major international cities such as Frankfurt and in specific local contexts such as intersections in Turkey or delivery routes in Linz. However, no published reports have been found on the case of Wels–Marchtrenk, an area lacking scientific analysis of its industrial congestion. This research seeks a solution to this issue by adopting approaches that have already been

tested elsewhere. Compared to previous work, the added scientific value of this study lies in integrating multiple strategies within a single coherent simulation for Wels–Marchtrenk, whether through adaptive traffic light optimization or the evaluation of a potential alternative truck route. All of this is measured in terms of both road performance (times, delays) and environmental impact (reduction of local emissions and CO_2).

Andras Varhelyi (2002) demonstrates how the mass factor in logistics can interfere with the efficiency of heavy goods vehicles (HDVs). He explains that the high mass of HDVs magnifies the energy required for acceleration, (F=ma), and signaled intersections represent a critical operational inefficiency. Varhelyi quantified this impact in a before-and-after case study conducted in Sweden, using car-following to measure the environmental effects of converting a signalized intersection into a roundabout. Key results showed drastic reductions in pollutants and fuel consumption by eliminating the complete stop cycle and the resulting idling time. Specifically, replacing a signalized intersection with a roundabout resulted in an average decrease in: Fuel consumption: 28%; CO emissions: 29%; NOx emissions: 21%. These findings validate that eliminating stop-and-go traffic in favor of smoother traffic flow is an exceptionally effective decarbonization strategy for heavy logistics fleets. [6]

Prioritizing freight transport by heavy goods vehicles on urban road networks has proven to be a highly effective solution. Since trucks tend to have a greater impact on traffic congestion and generate more emissions when stopped or moving slowly, granting them priority at specific intersections or road sections has been explored. Park, S., Ahn, K., & Rakha, H. A. (2019) studied the implementation of Freight Signal Priority using connected vehicle technology, through SUMO simulation in an urban corridor [7]. By coordinating traffic signals to give preferential right-of-way to connected trucks, network-level fuel consumption decreased by approximately 12%, while pollutant emissions fell between ~12% and 25% (depending on the pollutant, e.g., -11.8% for CO_2; -25.9% for NO_x). This suggests that prioritizing heavy goods vehicles at critical junctions (whether through adaptive traffic lights, advance warning systems, or dedicated lanes) can mitigate traffic congestion and reduce fuel consumption, resulting in lower emissions. However, implementation must be based on appropriate criteria and its effectiveness must be verified through simulation.

3. Simulation Framework Implementation

3.1 Network Preparation and Modeling

The simulation network was created using OpenStreetMap (OSM) data to accurately represent the B1 federal highway corridor between *Wels* and *Marchtrenk* in Upper Austria, shown in figure 1.
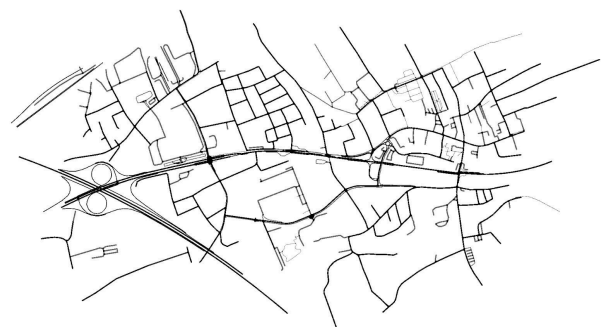

Figure 1: First draft of the original network of B1 corridor, taken from SUMO.

The import was performed through SUMO's OSM Web Wizard, which automatically converts map data into a simulation-ready network including road geometries, junctions, and traffic lights.

Figure 2: Clean network of B1 corridor, taken from SUMO.

After import, as it can be seen in figure 2, several clean-up and optimization steps were carried out to ensure realistic simulation behavior:

- Removal of minor residential and side streets not relevant for freight transport.

- Correction of missing or incorrect junction connections using *netedit*.

- Adjustment of edge IDs and naming to match the real B1 corridor structure.

- Calibration of lane numbers, speed limits, and intersection priorities based on local traffic data.

- Verification and manual alignment of signalized intersections along the corridor.

The final network covers approximately 6.5 km of the Linzer–Welser Straße, connecting the SPAR logistics center in Wels with industrial areas in Marchtrenk. This cleaned and validated model, shown in figure 3, serves as the base for all subsequent simulation scenarios.

Figure 3: Implemented roundabouts marked in a red square on the network of B1 corridor, taken from SUMO.

3.2 Fleet and Infrastructure Description

The logistics hub in Marchtrenk operates nine conventional diesel trucks (Mercedes Actros 2546 L, 460 hp, gross weight ≈ 26 t, refrigerated transport) [8][9]. These vehicles perform daily delivery tours throughout Upper Austria.

The site also includes a 7 000 m² photovoltaic (PV) installation providing a significant share of the facility's electricity demand, including potential vehicle charging [10].

In the baseline scenario, the fleet is modeled as diesel heavy-duty vehicles using SUMO's *HBEFA* emission classes. Travel times, stop durations, and emission outputs (CO_2) are recorded for this configuration.

In the alternative scenario, shown in the figure 4, the diesel fleet is replaced by battery-electric trucks such as the Mercedes-Benz eActros 600. According to manufacturer data, the eActros 600 charges from 20 % to 80 % in ~30 minutes at 1 MW stations and has a range of ≈ 500 km [11]. Given that daily routes remain below 200 km round trip, charging is assumed to occur primarily at the depot—powered by the on-site PV system.
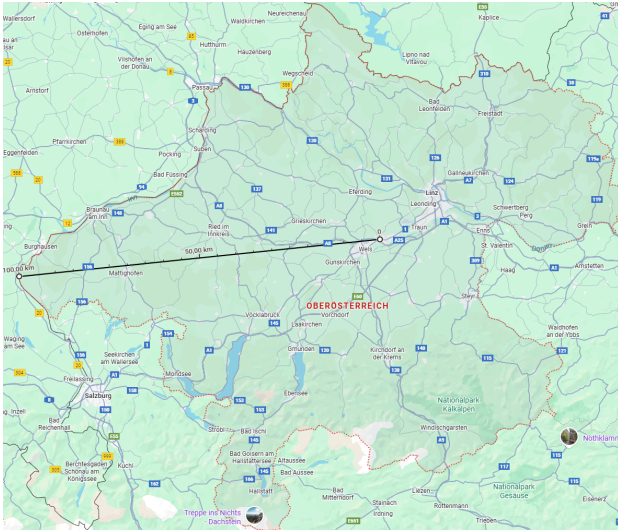
Figure 4: Maximum possible route length in Upper Austria from the central hub, illustrating that the distance can be easily covered by an electric truck on a single charge, and potentially even twice.

3.3 Scenario Definition

Two distinct simulation scenarios were developed:

1. Baseline (Current Situation):
   Diesel truck fleet operating under the existing fixed-time signal control along the B1 corridor.
2. Roundabouts:
   Replacement of traffic lights with roundabouts on critical junctions points in order to reduce traffic jams.
3. 50% e-Truck Adoption:
   Fifty percent of the fleet was replaced with e-Trucks in order to reduce emissions on the road.
4. Fully Electric Fleet:
   All trucks in the fleet deployed as e-Trucks to reduce emissions even further.

All scenarios are simulated under identical demand conditions, enabling a direct comparison of operational efficiency and emission performance.

3.4 Simulation Parameters and Configuration

The simulations were implemented in SUMO 1.24 using the following parameters:

Parameter	Value / Description
Simulation duration	7200 s (morning peak hours)
Step length	1 s
Network length	~6.5 km
Vehicles simulated	40 heavy trucks + background traffic
Vehicle types	HBEFA 3.2 heavy-diesel / e-truck
Emission model	SUMO Emission Model (HBEFA)
Energy model	Custom E-Vehicle integration
Speed limits	50 – 70 km/h

Traffic light control	Fixed-time

Traffic demand, delivery routes, and stop durations were derived from the operational schedule of the logistics hub.

All simulations were executed using SUMO's TraCI interface for dynamic data collection and scenario control.

3.5 Performance Indicators and Data Collection

The following key performance indicators (KPIs) were recorded to evaluate each scenario:

KPI	Description
Average travel time	Mean trip duration for freight vehicles
Total emissions	CO_2 output per simulation
Energy consumption	Fuel or electrical kWh used

Data was processed through Python scripts, enabling statistical comparison between scenarios.

3.6 Rationale and Expected Outcomes

Given the limited route radius (< 100 km one way) and the depot's existing renewable infrastructure, the electrified fleet is expected to achieve significant CO_2 reductions while maintaining operational efficiency.

The integration of coordinated traffic-light control is anticipated to further lower emissions by reducing idle time and stop-and-go patterns.

The developed SUMO simulation framework thus allows a direct quantitative comparison between the current diesel-based system and a sustainable, electrified logistics operation powered by renewable energy.

4. Results

The results obtained through SUMO simulation allow for a clear comparison of the impact of different freight transport optimization strategies on the B1 corridor (Linzer–Welser Straße) during peak hours (7–9 a.m.). Three distinct scenarios were compared: (1) a fully diesel-powered logistics operation under fixed traffic light control (baseline scenario), (2) a mixed fleet with 50% electric trucks, maintaining the current traffic lights, and (3) a 100% electric fleet accompanied specifically located roundabouts where currently major traffic jams are produced, with the intention of reducing unnecessary stops. The main objective was to quantify the impact of these configurations in terms of CO_2 emissions, energy efficiency, and travel times.

As can be seen in Figure 5, the total number of vehicles that completed their route during the simulated period increased significantly in the optimized scenario: from 3,318 (diesel) to 4,269 vehicles, representing a 28.7% improvement. This difference is attributed to the combination of two key factors: the elimination of prolonged stops due to the implementation of roundabouts, and the more efficient response of electric trucks to flowing traffic conditions.

This also directly indicates a considerable improvement in travel time for users who did complete the journey. Although it was not the primary objective of this project and simulation, lower average journey times were achieved in

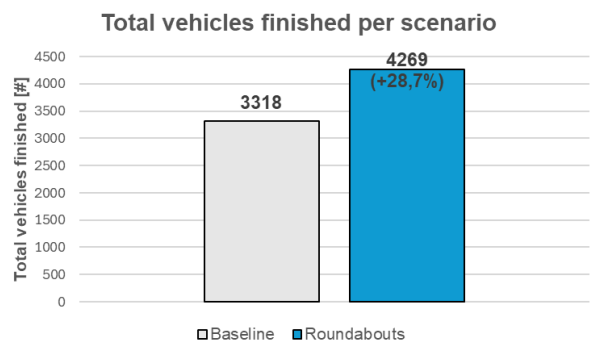the fully electrified scenario, with a reduction of up to 18% compared to the baseline scenario.

Total vehicles finished per scenario

Figure 5: Total vehicles finished per Scenario

As shown in Figure 6, which displays the total carbon dioxide (CO_2) emissions generated by each fleet configuration, it can be seen that for all-diesel trucks, emissions exceed 3,005 tons during the simulated period. By replacing half the fleet with electric vehicles, emissions are slightly reduced to 2,890 tons. However, the greatest difference occurs in the 100% electric scenario, where emissions drop significantly to 2,773 tons. This reduction is attributable to the complete elimination of direct exhaust emissions (tailpipe) and the fact that the electricity used for recharging comes mostly from a solar power plant installed at Marchtrenk's logistics hub, thus maximizing the environmental benefit.
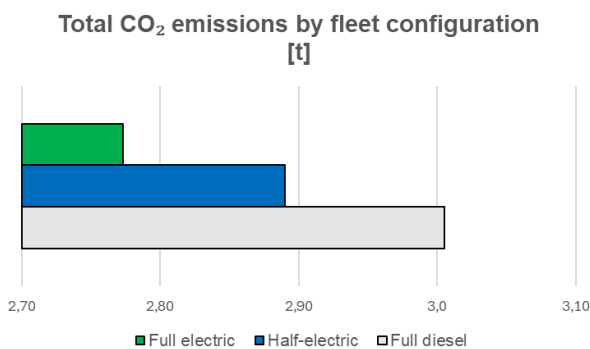
Total CO_2 emissions by fleet configuration [t]

Figure 6: Total CO_2 emissions by fleet configuration

Figure 7 quantifies the percentage reduction in CO_2 emissions compared to the baseline scenario. It shows that a mixed fleet achieves a 3.82% reduction in emissions, while full electrification allows for a 7.72% reduction, compared to the baseline scenario. Although these percentages may seem moderate, it is important to remember that they correspond to a single corridor during one hour of operation. Scaling this effect to a daily or weekly logistics operation, the cumulative impact is considerable in terms of sustainability.
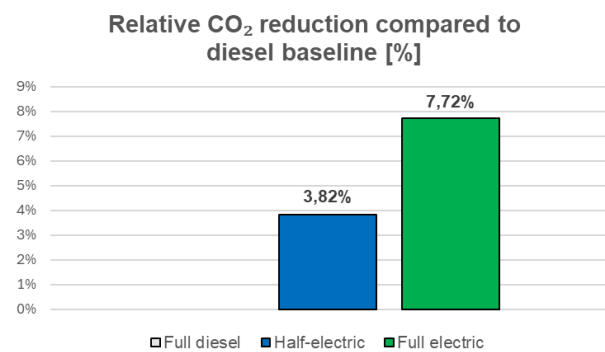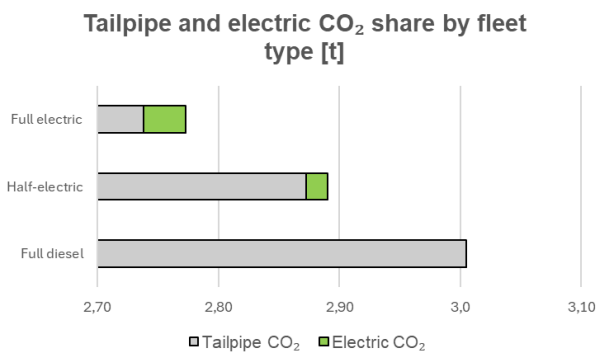
Relative CO_2 reduction compared to diesel baseline [%]

Figure 7: Relative CO_2 reduction compared to diesel baseline

To understand how CO_2 emissions can be broken down by source type and thus gain a clearer picture of the real difference in sustainability between the different scenarios, Figure 8 is presented, showing tailpipe emissions and emissions associated with electricity generation for electric vehicles. In the diesel scenario, all emissions come from the tailpipe (3,005 tons). In contrast, in the scenarios with electric vehicles, the contribution from tailpipe emissions decreases significantly (2,738 tons in a fully electric fleet), and the remaining emissions correspond to the electricity consumed, which are considerably lower (35,249 tons in a fully electric fleet). In the case of a fully electrified fleet, indirect emissions from charging are minimal thanks to photovoltaic power generation.

Tailpipe and electric CO$_2$ share by fleet type [t]

Figure 8: Tailpipe and electric CO$_2$ share by fleet type

5. Conclusion

The SUMO-based simulation of the B1 Linzer–Welser Straße corridor during peak-hour conditions demonstrates that both fleet electrification and targeted infrastructure optimization can meaningfully improve the performance and sustainability of freight transport operations.

Across the three evaluated scenarios—(1) baseline diesel fleet with fixed traffic lights, (2) diesel fleet with strategically added roundabouts, (3) a mixed 50% electric fleet combined with strategically added roundabouts, and (4) a fully electric fleet combined with strategically added roundabouts—the optimized configuration consistently outperformed the current operating model. The total number of vehicles successfully completing their routes increased by **28.6%**, indicating smoother traffic flow and reduced congestion when infrastructure bottlenecks, such as signalized intersections, were redesigned. This also led to improved travel times, with the fully electrified/roundabout scenario reducing peak-hour travel time by **up to 18%** relative to today's conditions. While not the primary goal of the study, this highlights that sustainable logistics interventions can simultaneously enhance user experience for all road participants.

From an environmental perspective, the study shows clear potential for emissions reductions. CO$_2$ emissions decreased slightly with a 50% electric fleet (**–3.82%**) and substantially with full electrification (**–7.72%**) when compared to the diesel baseline. When these reductions are interpreted beyond the two-hour simulation window and projected across typical daily operations, the cumulative benefit becomes significant. Furthermore, separating emissions by source demonstrated that electric trucks nearly eliminate tailpipe emissions, and that indirect emissions from electricity generation are minimal when renewable energy is available—such as the photovoltaic plant at the Marchtrenk logistics hub.

Overall, the results indicate that **combining fleet electrification with targeted infrastructure improvements offers synergistic benefits**, leading to reduced emissions, improved energy efficiency, and smoother corridor performance. These findings support the ongoing transition to sustainable freight transport within regional logistics networks.

6. Future work

While the study demonstrates clear benefits of fleet electrification and infrastructure redesign, several important directions for further research remain:

- **Full-day and multi-day simulation.**

  Extending the analysis beyond the morning peak would enable the evaluation of daily operational patterns, battery consumption across multiple trips, charging schedules, and cumulative congestion effects.

- **Integration of additional vehicle classes.**

  Future simulations should incorporate vans and buses with differentiated driving behavior to more accurately represent mixed traffic dynamics on the B1 corridor.

- **Microscopic safety and traffic-flow analysis.**

  The introduction of roundabouts should be examined further from a road-safety and traffic-flow perspective, including conflict point analysis, heavy truck maneuverability, and the impact on emergency vehicle accessibility.

- **TGW Hub**

  This work will gain additional relevance as TGW is currently expanding its logistics hub, scheduled for completion around 2026, where the proposed concept could be applied to optimize traffic flow and support future operational planning.

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