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Assessing the environmental impact of TSM: a case study of the city of Tampere

Angela Carboni*[1], Itir Coskun[2], Piotr Kaminski[3]

1. Politecnico di Torino, Italy

2. SWARCO Solution Center GmbH, Germany

3. SWARCO Technology APS, Denmark

Abstract

Urban transportation systems face increasing challenges from rising traffic volumes and their associated environmental impacts, necessitating innovative traffic management strategies. This study explores the environmental effects of traffic signal management (TSM) solutions, focusing on the transition from fixed-time control to advanced actuated and adaptive systems. A case study was conducted along a six-intersection urban corridor in Tampere, Finland, using microsimulation modeling integrated with emission evaluation tools. The methodology evaluates key performance indicators, including travel delays, stops, fuel consumption, and pollutant emissions, under varying traffic conditions. Aggregated analysis provides insights into corridor-wide impacts, while intersection-specific evaluations highlight localized variations shaped by traffic flow and geometric configurations. The study also underscores the importance of precise scenario characterization to enable robust comparative analyses and presents a replicable framework for assessing the environmental and operational benefits of TSM solutions.

Keywords: ITS, Environmental Impact, Emissions, Traffic simulation

Introduction

ITS systems leverage communication technologies to enable efficient management of transportation. In urban areas, where often different modes of transport operate together, the aim is to ensure safe and efficient mobility of people and goods. As the awareness around the global challenge of climate change has been increasing in the last decades, adding to the impact on safety and efficiency, understanding the environmental impact of ITS Solutions has gained importance.

This study analyses different types of intersection control algorithms with the specific objective of estimating their environmental impact through performance indicators (Coskun and Carboni 2024), defined based on the scientific literature review (Carboni and Coskun 2024). The main findings of the literature review underline the lack of available studies in quantification of the environmental impact of ITS solutions with detailed scenario description that is necessary to separate the impacts of what may be geometric aspects of the urban corridor, traffic flows or control logic from the environmental effects of the solutions. The goal of this joint study by SWARCO and the Polytechnic of Turin is to define a methodology to assess the environmental impact of a chosen ITS Solution, in this case signalized intersection control algorithms. Furthermore, the methodology is tested in a predefined area in Tampere, Finland. In this paper the case study and the evaluation results are explained in detail to, on one side, understand the impact of different types of intersection control algorithms, and on the other side, provide a transferable basis for further research on the methodology and other case study applications.

Methodology Description

Traffic simulation tools are widely used as it allows for understanding the isolated impacts of predefined inputs. The spatial scale of the simulation is mainly influenced by the type of ITS solutions to be analysed. In this study, based on the previously done literature review, the methodology is defined based on an urban corridor described according to the number of intersections and their spacing.

Figure 1 shows a schematic visualisation of the methodology phases. The following sections explain in detail the main elements composing each step.

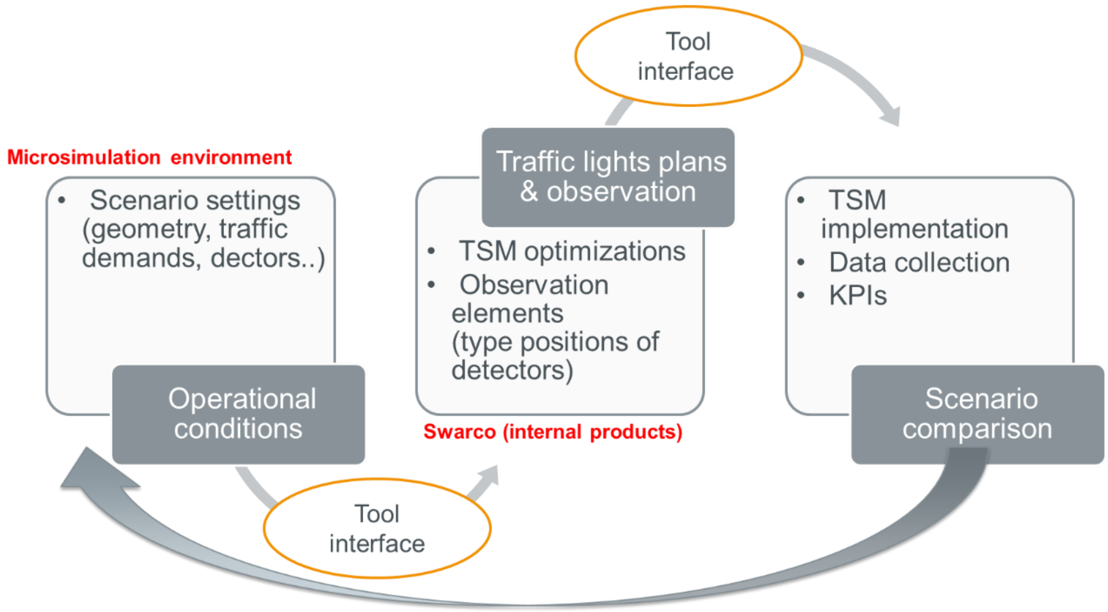

Figure 1- Methodology

Scenario Settings

The **main elements** that compose a scenario in a traffic microsimulation environment is defined as the operating conditions and can be classified into:

- Geometric elements that describe the spatial structure of the corridor:
  - Number of intersections and their distance in the corridor
  - Number and types of lanes for each intersection
  - Speed limits
- Flow pattern describes the manoeuvres at each intersection. Typically, the organisation of the manoeuvres is fixed for the case study; while, the percentage of traffic distribution may vary.
  - % of relevant mainstream, merging flows

  - 'Fixed' or 'variable' traffic flow during the simulation period
- Flow composition describes the travel demand volume
  - Total flow
  - Flow composition by % vehicle types
  - Traffic generation method (e.g. traffic state, Origin-Destination matrices)
- Public transport flow includes the PT lines, stops and timetable.
- Car following and lane changing model to describe the vehicle behaviour.
  - Car-following model simulates the behaviour of vehicles while following other vehicles travelling ahead in the same lane.
  - Lane-changing model simulates the decision-making process of drivers when changing lanes

The traffic signal management solutions may have different effects if the operating conditions differ. A solution may be more effective for an urban corridor with very close intersections or at increasing complexity of intersections. These elements differ for each case study. On the other hand, considering the same case study for which the geometric elements are typically fixed, other conditions such as speed limits or traffic volume and composition may influence their effects. For these reasons, it is important to describe the operating conditions of each simulated scenario to make a correct and complete comparison of the results.
Table 1 displays a summary table of the main parameters describing the typical urban corridor scenarios. Using images (maps) to show the geometric detail of intersections and detailed ad hoc tables for traffic composition is recommended.

Scenario_code	**baseline/ID**
n. intersection*	number
Avg. Intersection distance	meters
speed limit	km/h
total flow	n veh
traffic flow configuration**	base/base+20%/base+50%/other
traffic flow during the simulation	fixed/variable
traffic flow generation	traffic state/OD matrices
TSM (Traffic Signal Management)	base/actuated/coordinated/adaptive
PT	yes/no
intersection with TSM	no/all/specify
car following model	default/specified parameters
lane changing model	default/specified parameters
description	brief description of the scenario
*	*intersection detail (map)*
**	*traffic detail composition*

Table 1 - Scenario description and main elements

Performance Indicators

Performance indicators from literature are typically available in traffic microsimulation environments and can be collected for the urban corridor (system) or for each intersection. The model usually includes not only the urban corridor under study but also a portion of the surrounding road network, thus, when analysing aggregated system data, it should be noted that those road sections will also be included.

Typical indicator to describe the congestion level are travel time, delay, the number of vehicles in a queue, the average speed, the number of stops during the path, and the LOS of each intersection. The LOS (Level of Service) measures the operational conditions within a traffic stream, generally in terms of travel time, speed, freedom to manoeuvre, traffic interruptions, comfort, and convenience (Transportation Research Board 2000). The emission values of air pollutants and greenhouse gases (GHG) are calculated using specific emission models integrated into the EnViVer Pro tool, which operates within the PTV VISSIM microsimulation software. The name of the indicators and the unit may change based on specific traffic simulation software.

Case Study

The case study area is an urban corridor consisting of six intersections in the city of Tampere, Finland. The intersections are located on the *Hämeenpuisto street* with an average of 150 meters distance from each other. The model of the corridor and the surrounding network, shown in Figure 3, was built in PTV Vissim traffic microsimulation software. Actuated and adaptive intersection control modes were simulated in PTV VISSIM using a dedicated interface designed to model these control modes within the simulation environment.

This section shows the preliminary results to test the proposed methodology.

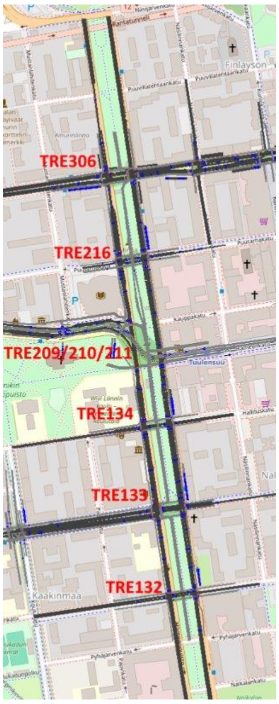

Figure 2- Tampere corridor and intersections code

Traffic Signal Management (TSM) Solution

Within the scope of this case study, three control modes are included in the simulations:

- Fixed-Time Signal Control: Signal group requests and green extensions are fixed and do not respond to real-time conditions. This method relies on predetermined signal plans, often based on historical traffic data, and is typically used in predictable or low-variability environments.
- Vehicle-Actuated Control (VA): Requests and green extensions are managed dynamically based on detection zone inputs, within pre-defined minimum and maximum green time limits and extension gaps. The system reacts to actual vehicle presence, offering a more responsive approach than fixed-time control, though it still operates within set boundaries and does not optimize across intersections.
- Adaptive Intersection Control: Smart Intersection Control (SI) is used in this study which is an adaptive intersection control solution developed by SWARCO. Smart Intersection dynamically adjusts green times at individual intersections based on real-time traffic demand. Vehicles, cyclists, and pedestrians benefit from optimized signal changes that reduce delays and improve safety. The system continuously learns from traffic flow variations, refining its decisions to maintain peak efficiency. Optimization decisions are based on detailed traffic characteristic measurements, including consecutive vehicle gaps and headway analysis. These measurements help assess changes in saturation flow, guide capacity estimates, and determine optimal green time patterns that best match actual traffic conditions. It is an innovative approach having such a powerful adaptive traffic control logic build in the controller software.

Scenarios

The three types of traffic signal management solutions simulated in this study are analysed for two different types of scenarios. While the rest of the operating conditions stay the same, the second type of scenario differs from the first one with higher level of traffic volume fed from the side branches of the analysed urban corridor. This is defined in order to assess the impact of these traffic signal management solutions. This scenario was designed with sufficient traffic values to create challenges for traffic light control without saturating the network when applying fixed traffic light control.

Each TSM Solution is simulated for each of the scenario to see their impact with varying traffic volumes. 6 simulation results are obtained from this study. Table 2 shows the scenario compositions with numbers indicating the type of scenario and letters indicating the type of the TSM solution simulated. The public transport lines are not included in the scenarios. Figure 3 shows the simulated corridor with feeding traffic from the side branches until the volume along the corridor was increased.

Scenario_Code	**1A**	**1B**	**1C**	**2A**	**2B**	**2C**
N. Intersection	6	6	6	6	6	6
Avg. Intersection Distance	150	150	150	150	150	150
Traffic Flow	base	base	base	increased	increased	increased

Configuration						
Traffic Flow During The Simulation	fixed	fixed	fixed	fixed	fixed	fixed
Traffic Flow Generation	traffic state	traffic state	traffic state	traffic state	traffic state	traffic state
Tsm	fixed	actuated	adaptive	fixed	actuated	adaptive
Pt	no	no	no	no	no	no
Intersection With Tsm	all	all	all	all	all	all
Car Following Model	default	default	default	default	default	default
Lane Changing Model	default	default	default	default	default	default
Description	baseline	base scenario with vehicle actuated mode	base scenario with Smart Intersection (adaptive traffic control)	increased traffic	increased traffic with vehicle-actuated mode	increased traffic with Smart Intersection (adaptive traffic control)

Table 2 – Scenario compositions

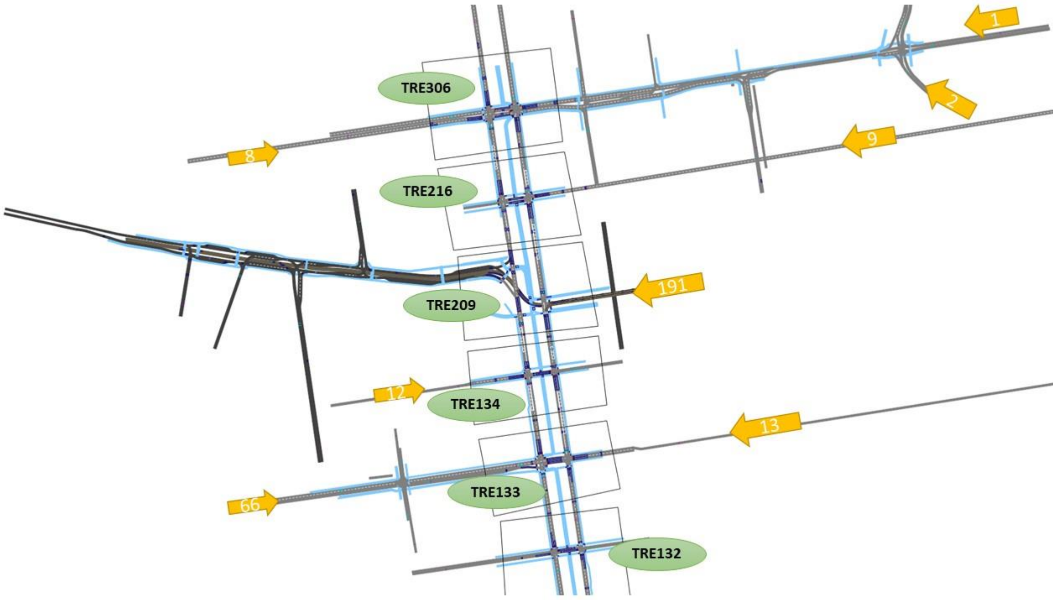

Figure 3 - simulated intersections with feeding traffic from the side branches

Results

Figure 4 and Figure 5 summarizes the results of the case study comparing the results of six scenarios for the simulated urban corridor. Figure 4 shows the average delay and number of stops for the simulated vehicles. The blue bars that represent the second type of scenario, are higher as the increase in traffic is a direct cause of the increase in average delay. In the two scenarios with fixed-time signal control (1a and 2a), the delay and stops double. When looking at the first type of scenario with relatively lower traffic volume, the introduction of an actuated signal control system (1b) shows a reduction in average delay of 13% (1b-1a). Whereas the impact of an adaptive signal control system in this type of scenario (1c) in comparison to actuated is rather marginal with a difference of 2% (1c-1b).

However, when looking at the second type of scenario with increased traffic volume, the differences between the impact of these three signal management control systems are rather significant. In this setting, adaptive traffic control system shows a significant reduction in average delay and average number of stops with 50% (2c-2a for average delay) and 52% (2c-2a for average n of stops) respectively in comparison to fixed time signal control systems. Similar results can be seen for the average speed in Figure 5. The impact of actuated and adaptive signal control systems is larger in scenarios with increased traffic volume that stresses the network.

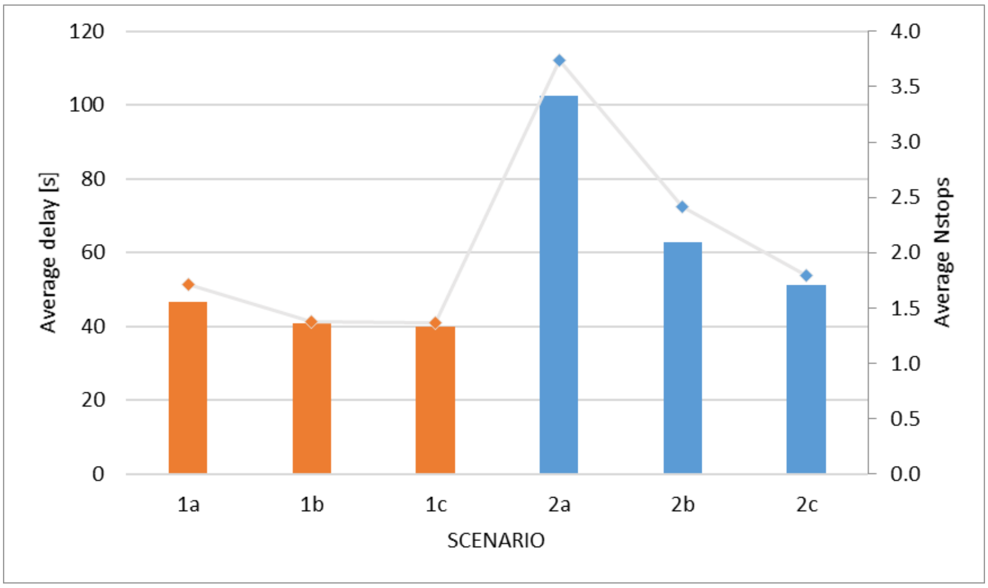

Figure 4 - Average delay (bars) and number of stops (points) for the six scenario compositions

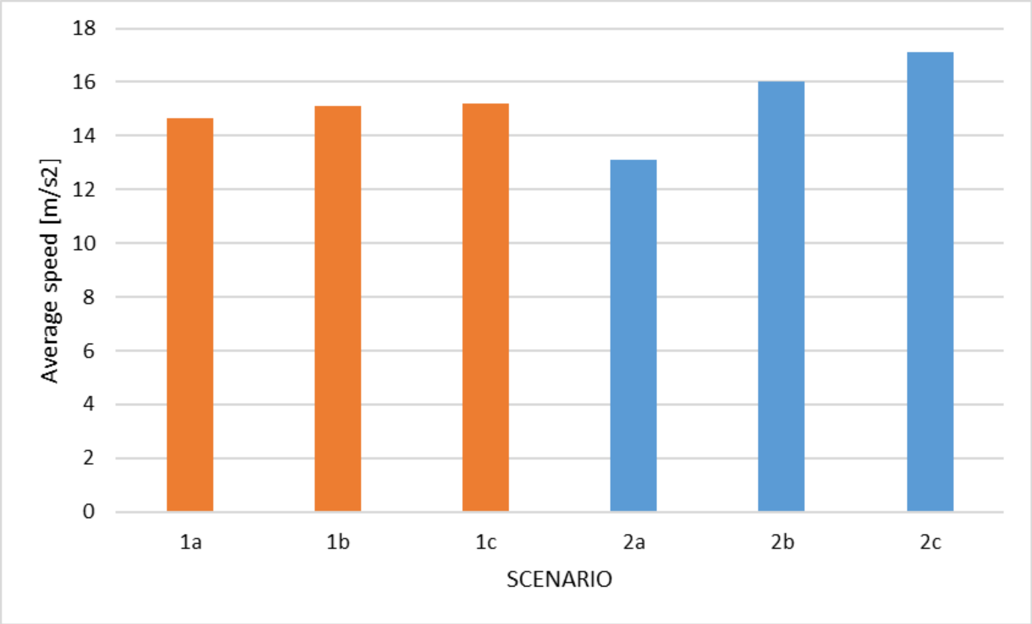

Figure 5 - Average speed for the six scenario compositions

When looking at the level of service (LOS) indicator, it can be seen that it is not homogeneous in the corridor, showing variations between intersections and scenarios. The impact of the increased volume between two scenario types (1a and 2a) can be seen the most in intersections TRE216 and TRE133 (see Figure 2 for intersection codes). In summary, adaptive intersection control improves all intersections' LOS greater than or equal to C.

As regards to the environmental benefits of selected TSM solutions, fuel consumption levels correlated with GHG emissions is visualized in Figure 6. As expected, consumption increases as traffic volume increases, however, this increase is not identical across intersections. Similar to the observation of changes in LOS across scenario type one and type two, intersections TRE216 and TRE133 show the biggest increase in fuel consumption. In general, the peak in fuel consumption due to increased traffic shows reduction with the introduction of actuated and adaptive traffic light control systems, with the effect being the greatest with intersections with higher fuel consumption levels. The positive effect of these signal control systems is smaller in scenario type one with lower traffic volumes.

Lastly, change in the pollutant levels among six scenario compositions are visualized in Figure 7, the trends of the three pollutants are comparable across each scenario. The environmental benefit of the introduced TSM solutions is evident at all intersections except for the TRE134 intersection, which presents somewhat unexpected behaviour however holding the lowest values among other intersections. Similarly, for air pollutants, the largest difference in terms of reduction in % is seen for the two critical intersections, TRE216 and TRE133, with up to 44% and 43%, respectively (2c-2a). For the rest of the intersections the decrease is similar between scenarios "b" and "c" except for the two mentioned for which an adaptive system is shown to be more effective.

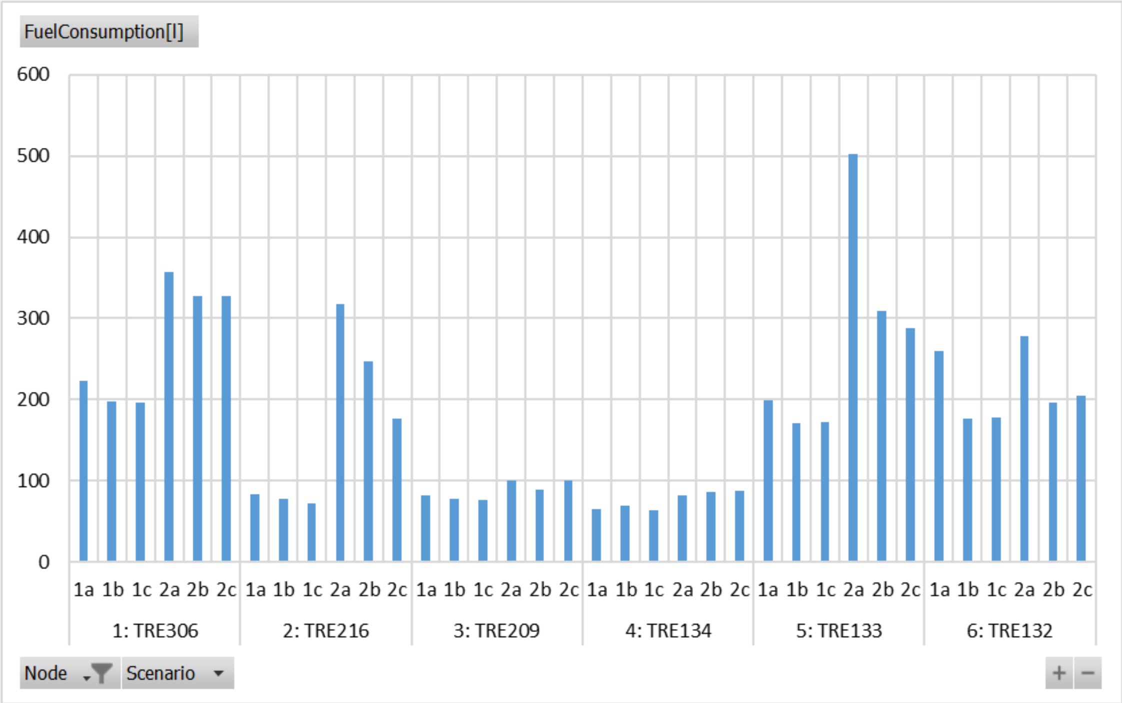

Figure 6 - Fuel consumption for vehicles in each intersection in simulated scenario compositions

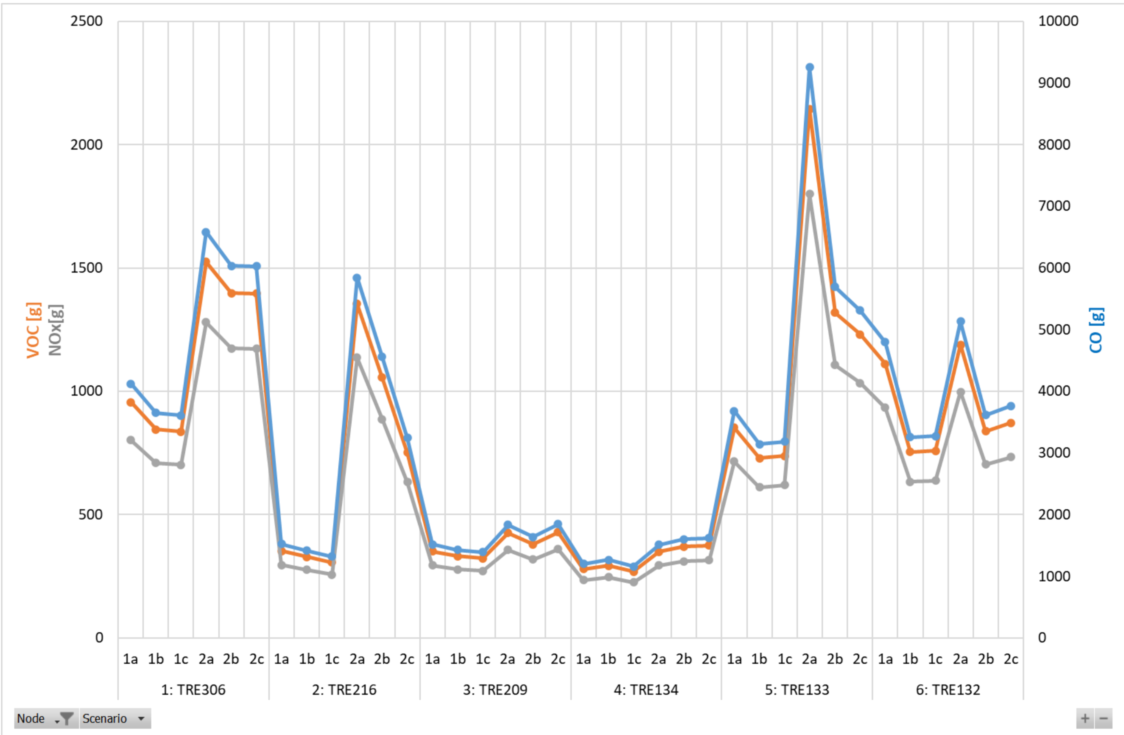

Figure 7 - Pollutant gas emissions (VOC, NOx, and CO) for the 6 scenario compositions

Conclusion

Traffic signal management (TSM) solutions exhibit varying impacts under different operational conditions, reaffirming the necessity of a precise and comprehensive characterization of simulated scenarios for robust comparative analyses. As a key principle when defining the methodology, this study aimed to demonstrate the critical role of accurately defining scenario parameters, enabling the evaluation of aggregated and intersection-specific effects of TSM solutions.

The findings indicate that aggregated analysis provides a broader perspective on corridor-wide performance, while intersection-level analysis offers insights into localized variations influenced by traffic volumes and geometric configurations. Across six simulated scenarios, the transition from fixed-time control to actuated and adaptive systems resulted in substantial reductions in delays, stops, and emissions, with the most significant improvements observed under higher traffic volumes.

To refine the proposed methodology, future work may consider the temporal dynamics of performance indicators, incorporate additional scenario variables such as vehicle mix and speed profiles, and test its applicability across urban corridors with diverse geometric and operational characteristics. Such advancements will allow for further validation of the methodology and contribute to a deeper understanding of the environmental and operational benefits of advanced traffic signal control systems.

References

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