Beyond Traffic Congestion: Developing Digital Twin to Enhance Accessibility to Points of Interest

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Abstract. The growing phenomenon of traffic congestion in urban areas, due to increasing motorization rates, has significant social, economic and environmental impacts. High vehicle congestion results in longer travel times and reduced accessibility to Points of Interests (POIs), especially during peak hours. While traditional strategies have prioritized infrastructure development, recent policies targeting the reduction of avoidable car journeys have shown some success in decreasing vehicle flows. However, it is crucial that these policies also develop measures to improve the accessibility of those who are dependent on the private car for their mobility due to the lack of modal alternatives, still existing in many areas.

To address these issues, a comprehensive approach is proposed based on microsimulation of vehicle flows, developing a small-scale digital twin, to replicate daily operating conditions. The methodology consists of several steps: (i) supply reconstruction through microsimulation model, (ii) demand analysis driven by advanced surveys and sensor technologies, (iii) evaluation of intervention scenarios aimed at optimizing the use of resources and minimizing infrastructure interventions.

The application of this methodology, tested on a real case study, consists of a main road in the urban area of Catania, characterised by high traffic volumes due to its strategic position and the presence of two attractive poles. It shows how targeted interventions, such as the improvement of road signs and the optimized management of car park entrances, can be effective solutions for improving accessibility and vehicle movements. Future developments will extend the model to assess the impact on the surrounding road network and to evaluate long-term interventions.

Keywords: Traffic microsimulation · Digital twins · Urban mobility · Traffic management · Urban accessibility

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1 Introduction

Mobility planning plays a key role in urban areas, as it makes it possible to limit vehicle congestion, an increasingly widespread phenomenon that has a negative impact on quality of life, the environment and transport efficiency [1, 2].

At national level, this phenomenon is very significant: in fact, Italy has one of the highest motorisation rates in Europe. According to Eurostat [3] there will be 694 cars per 1,000 inhabitants in 2023, which is higher than the EU average of 571 cars per 1,000 inhabitants. Moreover, the Italian car fleet is growing steadily, with an average annual increase of 1.3% since 2018, a higher rate than in other major European economies such as Germany (+0.7%), Spain (+0.4%) and France (+0.3%). At the urban level, some Italian cities are well above the national average, such as Catania, with 815 cars per 1,000 inhabitants. These data highlight the need for effective mobility planning strategies to mitigate the negative effects of high vehicle density [4, 5].

In recent years, despite policies to discourage car use, such as the introduction of Limited Traffic Zones (LTZs) and Low Emission Zones (LEZs) [6, 7], motorisation rates have not decreased significantly. At the same time, modal shift to public transport has not achieved satisfactory results, highlighting the need for more integrated strategies and complementary interventions to make mobility alternatives more attractive and efficient [7].

This modal imbalance in favour of private transport over public transport may be the result of a poor public transport supply, characterised by a limited territorial coverage, a low frequency of trips and an insufficient level of integration between the different modes of transport [8].

The lack of adequate public transport planning combined with insufficient dedicated infrastructure further limits the potential for effective modal shift. In order to stimulate a significant modal shift, an upgrading of the public transport system through investment in infrastructure improvements, favourable pricing policies and innovative solutions, such as the promotion of shared mobility and on-demand services, is essential [9, 10].

The result is imbalance between transport demand and supply, which forces users to rely on private cars, particularly to reach specific destinations such as hospitals, schools, universities and employment areas. These journeys, often linked to well-defined timetables and schedules, fuel the creation of real urban hotspots where the demand for mobility exceeds the response capacity of the public transport system, further exacerbating congestion and increasing the burden on road infrastructure.

To address and solve this problem, one possible solution to the modal imbalance lies in transport system optimisation, which can be supported by modelling and simulation of the urban transport system [11]. Such techniques allow a detailed assessment of the current state and critical issues related to mobility management, providing a precise view of traffic flows and nodes within the city. In addition, by simulating alternative management scenarios, both short and long term, it is possible to test the effectiveness of different strategies without the risk of implementing real interventions without prior evaluation. Different mobility management scenarios can be designed, distinguishing between long-term interventions, which involve significant changes to the transport system and the implementation of new infrastructure, with a time horizon of 10–15 years, and short-term interventions, which focus on targeted actions and rapid improvements to

existing infrastructure, with an implementation period of around 2 years. These scenarios allow critical issues to be addressed in a differentiated manner, optimising available resources and responding to immediate needs in a timely manner, without compromising the long-term vision.

Modelling at different scales, both macro and micro-simulation, using advanced traffic flow analysis and mobility management software, provides an in-depth understanding of the transport system from both a qualitative and quantitative point of view. By measuring specific indicators such as vehicle saturation rates, travel times, time lost, queues, service levels and public transport efficiency, it is possible to identify optimal solutions to improve mobility management, reduce congestion and promote accessibility to strategic points in the city.

Within this framework, the concept of a Digital Twin is introduced as a core component of the analysis. A digital twin refers to a virtual representation of a physical system, in this case, a section of the urban road network, capable of replicating its dynamic behavior under different conditions [12–14]. Through the integration of simulation models and real-world data collected via sensors and surveys, the digital twin allows for continuous calibration and testing of various scenarios [15, 16]. This enhances decision-making by providing a flexible and data-driven environment for evaluating targeted interventions in terms of their impact on accessibility and overall network performance [17].

The main tools available to develop the base model of Digital Twin include VISSIM and VISUM, which allow microscopic simulation and macro-level planning respectively, but also AIMSUN [18, 19], a versatile traffic simulation software that integrates both microscopic and mesoscopic simulation, and TransModeler, which provides powerful simulation capabilities for detailed analysis of traffic behaviour. Other useful tools include MATSim, for multi-agent simulation of modal choice, and Synchro, for traffic light and intersection design and optimisation.

Microsimulation tools like VISSIM are widely used for assessing traffic flow quality and Level of Service (LOS) on complex freeway facilities and intersections [20, 21]. These models can evaluate various scenarios, such as signal control applications at roundabouts [21] and the impact of pedestrian numbers on intersection performance [22]. However, proper calibration and validation of microsimulation models are crucial for obtaining meaningful results.

The objective of the paper is to propose an integrated approach based on microsimulation of vehicle flows, developing a small-scale digital twin to replicate daily operating conditions. The methodology is structured into several phases: traffic supply reconstruction through a microsimulation model, demand analysis using advanced surveys and sensor technologies, and evaluation of intervention scenarios aimed at optimizing resource utilization while minimizing infrastructure modifications. The proposed approach has been tested on a real-world case study involving a main urban road in Catania, characterized by high traffic volumes due to its strategic location and the presence of two major attraction poles. The results demonstrate that targeted interventions, such as improved road signage and optimized car park entrance management, can effectively enhance accessibility and vehicle flow.

The paper consists of five sections: Sect. 1 introduces the research by identifying the problem and providing a literature review on its implications and potential solutions.

Section 2 outlines the methodological approach and describes the data sources used for the analysis. Section 3 presents the case study, detailing its context, characteristics, and relevance to the problem under investigation. Section 4 discusses the results, interpreting the findings in relation to the research objectives and comparing them with existing studies. Finally, Sect. 5 concludes the paper by summarizing the key insights, highlighting the study's contributions, and suggesting directions for future research.

2 Methodological Approach

The proposed methodological approach follows a multi-step process to implement a robust microsimulation model with a view toward developing a digital twin. First, traffic data collection integrates multiple sources, including sensors, cameras, and radar, ensuring a comprehensive dataset for model calibration and validation. The next step involves the reconstruction of travel demand by analysing the routes between the various O/D pairs to identify possible itineraries along the road network. In parallel, the supply-side reconstruction consists in defining network characteristics and operational conditions. Then, the interaction between demand and supply is modelled to capture system behaviours. Finally, scenario analysis is conducted to evaluate different interventions, technological innovations, or infrastructure management modifications, providing insights into enhancing system accessibility under varying conditions.

The procedural steps are listed below and schematized in Fig. 1:

- Data collection (i.e. demand data and supply data);
- Demand reconstruction;
- Reconstruction of the transport supply;
- Supply-demand interaction and scenario analysis.

2.1 Data Collection

This phase involves the collection of all the required data for the reconstruction of the transport simulation model. Specifically, data can be divided into two main categories: supply data and demand data.

The data required to reconstruct the supply model includes all the infrastructure characteristics of the road network, such as the number of lanes and width, the priority rules, the presence of impedance elements (i.e. obstacles, discontinuity, gradient) and other geometric and functional characteristics. The data required for demand modelling consists of vehicle flows measured at of on-site monitoring sections. The positioning of these sections must be carefully planned in accordance with the reconstruction of the routes used by vehicles because, after that, the observed flows must be assigned to the travel paths, following the information obtained during the survey campaign.

To conduct field surveys, the study area must be zoned, within which all possible permitted manoeuvres are identified, including any manoeuvres that are not permitted according to the Italian Highway Code (from Italian "Codice della Strada"). The choice of technology to perform the survey depends on the complexity of the section to be analysed. For sections characterized by a limited number of manoeuvres, manual counting can be employed, involving an operator recording the passage of vehicles on printed

tables, organised in separate quadrants for each vehicle category. For more complex sections, it is advisable to use sensors based on radar technology, able to automatically detect the passage of vehicles, speeds and vehicle classification on a continuous 24/7 basis. However, these sensors could be subject to the phenomenon of obscuration in case of congestion or illegal parking. In this case, one solution may be the use of cameras for image acquisition and further processing. This second solution, using artificial intelligence algorithms [23], allows not only automatic counting of vehicles, but also their classification according to vehicle category, travel speeds and identification of illegal manoeuvres.

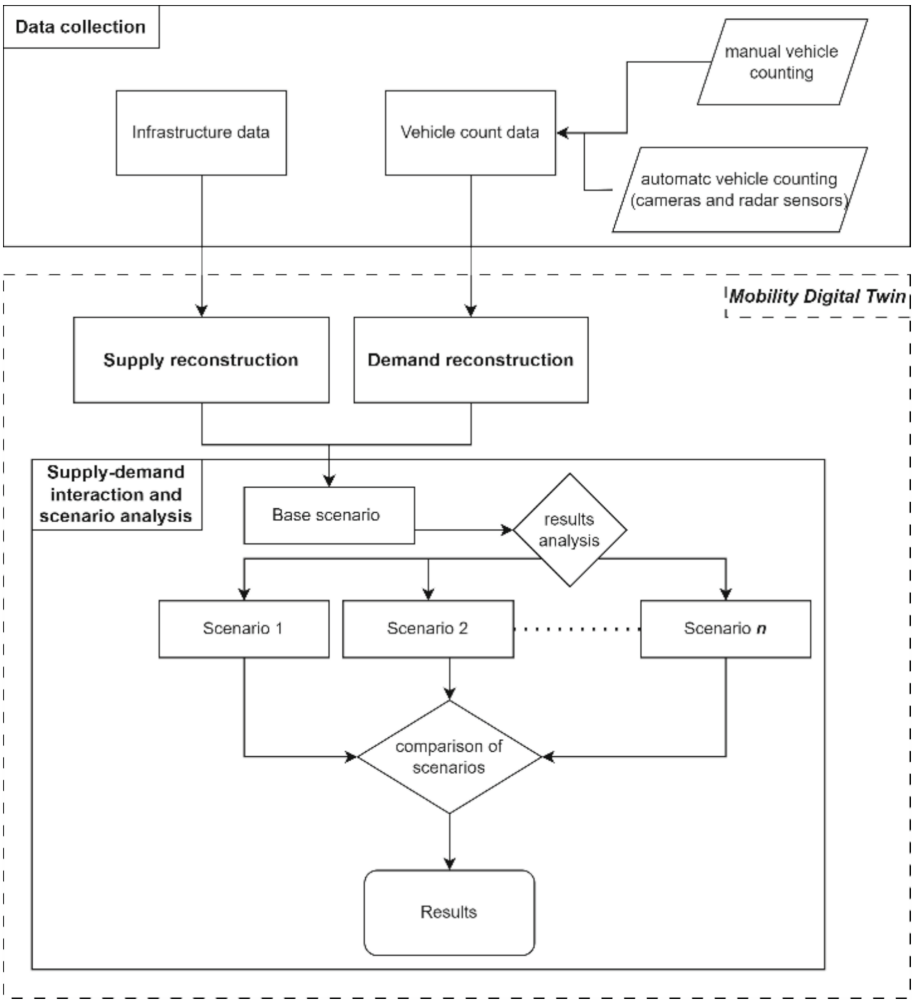

Fig. 1. Methodological framework for developing Digital Twin

2.2 Demand Reconstruction

This second phase involves processing and analysing the travel demand data. In this regard, it is necessary to examine the results from the survey campaign to identify the most critical time intervals and to define peak hours to be used as a reference for reconstructing of the demand matrix. Then, it is required to identify all possible routes between origins and destinations within the network and assign vehicle flows upon them considering the inputs derived from data collected within the counting sections. This allows to obtain a coherent representation of mobility demand within the analysed transport network.

2.3 Reconstruction of Transport Supply

The reconstruction of the transport supply involves the definition of the road network graph, which consists of links representing the lanes with their operational characteristics (i.e. number of lanes, width, travel directions, etc.) and connectors identifying turning manoeuvres. This operation must be closely integrated with the data collection phase, as the in-field survey can support an accurate characterisation of the road graph. At this stage, it is also necessary to identify and define and manage the conflict areas at junctions, generated by the interaction between traffic flows that intersect or overlap in space and time.

2.4 Supply-Demand Interaction and Scenario Analysis

After the reconstruction of both supply and demand, vehicle flows are simulated through the application of the Wiedemann 74 car-following model. Through traffic simulation we can reproduce traffic dynamics and evaluate the performance of the road network under different conditions. The main Key Performance Indicators (KPIs) used in the scenario analysis are level of service (LOS), travel time and queue length, evaluated on each analysed route. The level of service (LOS) assesses traffic quality on the simulated routes, considering speed, density, travel time and queue length. It follows the HCM classification, from LOS A (free flow) to LOS F (congestion). The analysis can be carried out at different level of details: focusing on junctions and evaluating single manoeuvres or at the network level, examining the formation of queues in specific road sections and the travel times within the study area. Based on critical points identified at this stage, it is possible to define scenario interventions and quantify the impact of the proposed solutions to improve network performances.

3 Case Study

Our methodological approach has been applied to a real case study consists of a main road in the urban area of Catania. Catania is one of the main metropolitan cities in Sicily, Italy, with an urban area of about 180 square kilometres and a population of about 300,000. However, its functional urban area extends well beyond the city boundaries and includes numerous neighbouring municipalities whose inhabitants daily commute to Catania for

work, education and access to other essential services. This high influx of commuters constitutes a significant transport demand, resulting in heavy congestion, longer travel times and a general decline in network efficiency. One of the main challenges contributing to this issue is the limited effectiveness of the public transport system, which does not provide adequate coverage and frequency in different across the city. As a result, in some of these areas, particularly those where essential services such as health, education and administrative offices are concentrated, remain largely inaccessible without the use of private vehicles.

3.1 Territorial Framework

Due to the commuting phenomena, the main traffic routes coincide with those which serve the function of penetration into the city. Among these, Via Santa Sofia stands out, both for the high intensity of traffic flows and for the presence of many attractive Point of Interests (POIs). This urban roadway originates in the north of the district named Cibali and runs in a northerly direction crossing the ring road of the city (Fig. 2).

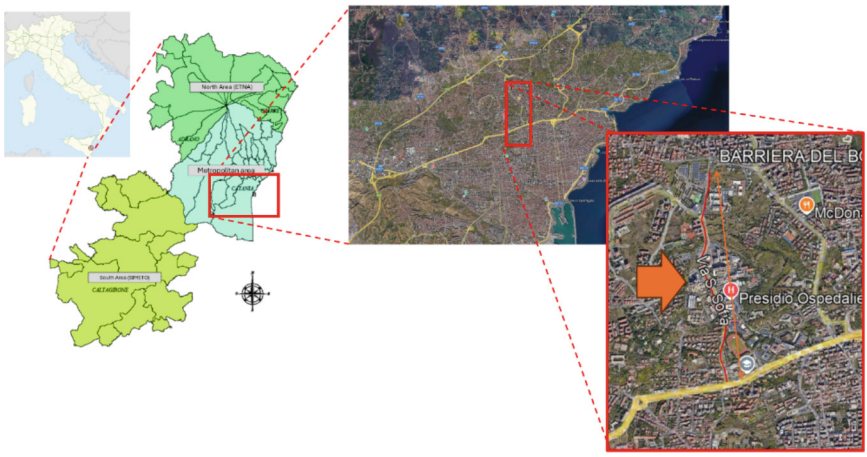

Fig. 2. Territorial framework

In recent years, the study area has seen a significant increase in the number of POIs, i.e. the University, the Polyclinic and the Biological Tower, resulting in a substantial increase in vehicle flows (Fig. 3).

In parallel, the road configuration has been changed several times (Fig. 4). The first, which was introduced in 2013, consisted in the implementation of a dedicated lane for the Bus Rapid Transit line BRT1. The more significant intervention, implemented between 2017 and 2018, involved the addition of two new turnarounds (Fig. 5).

3.2 Data Collection

The surveys have been carried out on nine monitoring sections along Via Santa Sofia. As shown in Fig. 6, these sections are classified according to their purpose: orange

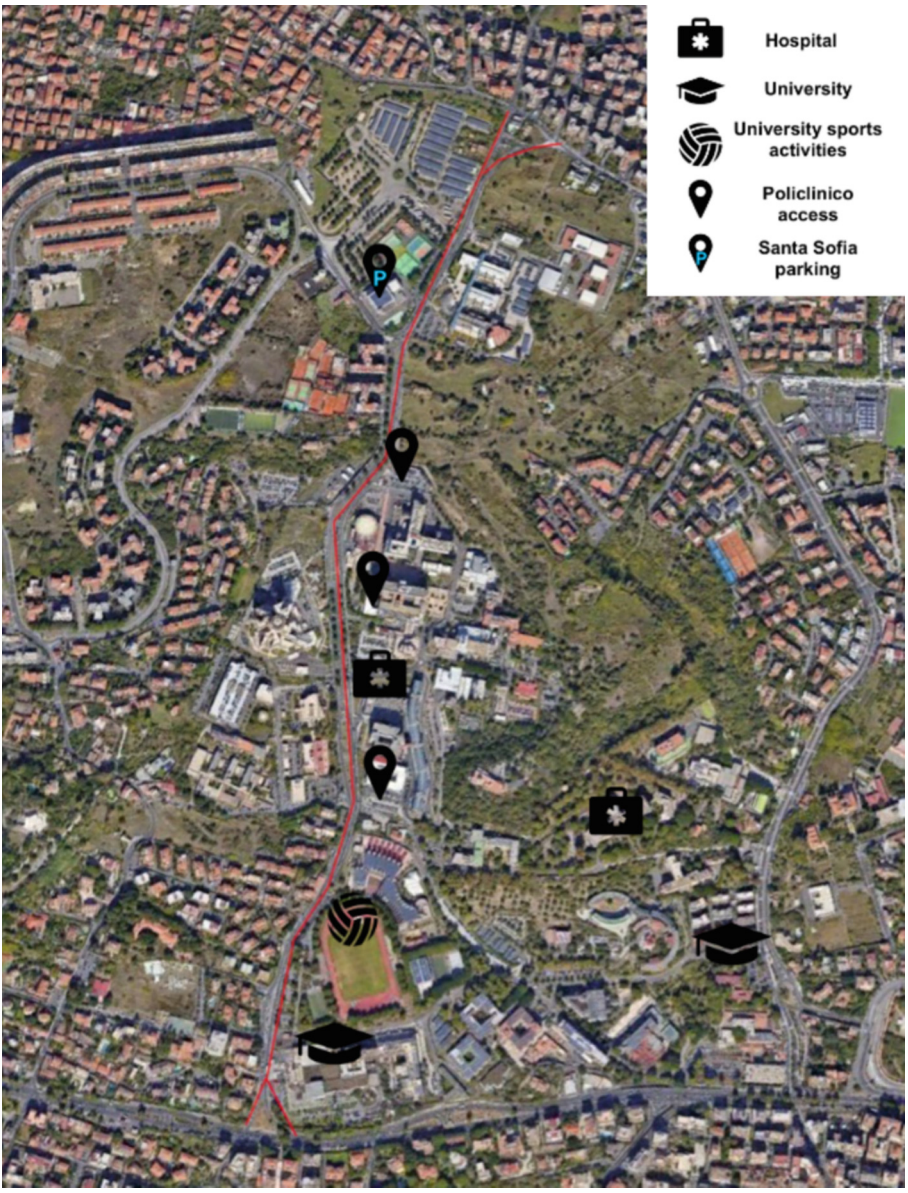

Fig. 3. Location of Point of Interests (POIs)

indicates segments monitoring through traffic on the road network, while blue refers to those monitoring vehicle movements access and egress from car parking facilities.

All sections have been monitored through manual counts carried out by operators using printed tables. In addition, surveys with sensor radar and cameras have been carried out at points 1, 2 and 3 (shown in green). In particular, the cameras have detected for

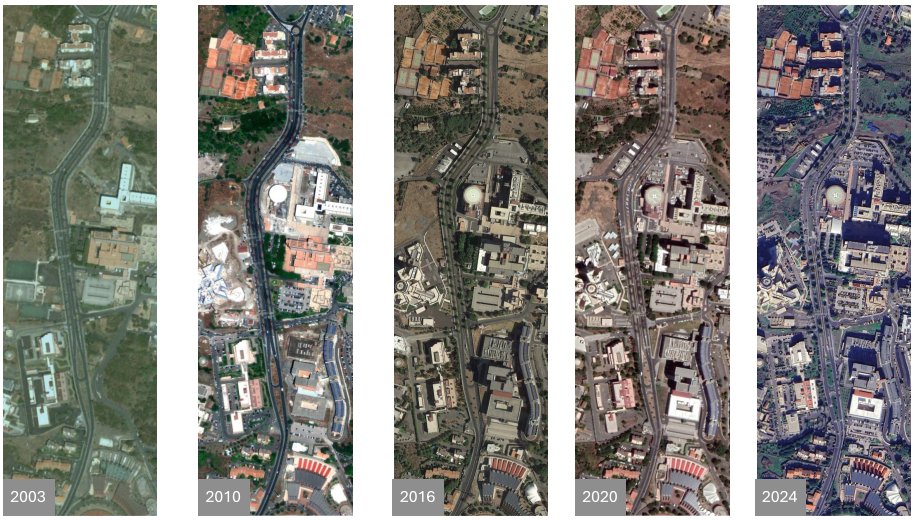

Fig. 4. Expansion of the urban area in Via S. Sofia

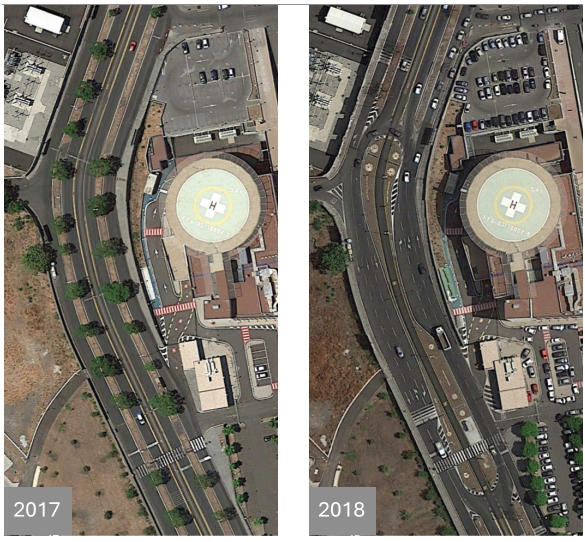

Fig. 5. Change Road configuration

the same duration as the manual surveys, while the radar sensor surveys started three days before the manual survey campaign and lasted a total of six days. The radar sensor surveys have been also used to analyse the traffic flow trends during the day within the area and to identify peak hours.

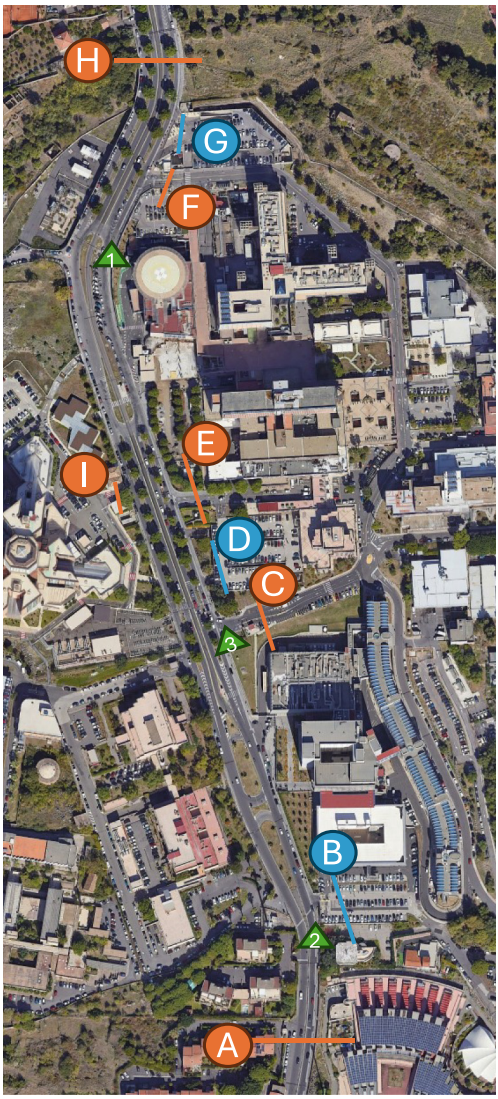

Fig. 6. Monitoring sections

3.3 Simulation Model Implementation

Then, the entire transport network has been reconstructed through a microsimulation model using VISSIM software (see state of affairs in Fig. 7). The model simulates all vehicle lanes and the two pedestrian crossings with traffic lights. The detected flows have been assigned as traffic flows to each identified path, based on the demand analysis. In addition, traffic signs and priority rules have been modelled, and a calibration of Wiedmann parameters has been carried out to better simulate user behaviour.



Fig. 7. Microsimulation model network in VISSIM

4 Results and Discussion

This section presents the results obtained through the simulation model. First, the current state is analysed to highlight emerging criticalities and guide the proposal of targeted intervention strategies. These strategies led to the definition of three different scenarios with incrementally applied solutions. Their outcomes are then compared with the baseline to evaluate overall effectiveness. The analysis focuses on key performance indicators such as travel time and queue length, which directly influence the perceived and actual quality of the driving experience. By reducing travel times and congestion, the proposed interventions improve users' ability to reach their destinations more efficiently, thereby contributing to greater accessibility at the network level.

4.1 Results of the State of Affairs

Once the state model had been reconstructed, initial analyses were carried out. As shown in Table 1, the obtained results highlight numerous criticalities in almost all the analysed manoeuvres, with a level of service at the lowest value. Furthermore, both travel times and queue lengths are particularly high, indicating a situation of generalized congestion along the section under study.

Table 1. Scenario 1 results, LOS, Travel time and Length of queue

Path	LOS
A-B	F
A-C	F
A-D	F
A-E	F
A-H (outer lane)	F
A-F	F
A-G	F
A-H (BRT1 lane)	F
A-H (inner lane)	F
B-H (outer lane)	F
C-A	F
C-H (outer lane)	F
H (outer lane)-A	C
H (outer lane)-C	F
H (outer lane)-D	F
H (outer lane)-E	F
H (outer lane)-F	F
H (inner lane)-A	D
H (inner lane)-G	F

Path	Travel time
A (from start of street) - H (inner lane)	7,36 min
A (from start of street) - H (outer lane)	9,07 min
A (from start of street) - H (outer lane)	2,70 min

Section	Length of queue
1	790 m
2	524 m
3	330 m

This confirmed what has already been observed during the survey phases, which revealed several critical issues, including illegal manoeuvres, significant slowing and stop-and-go of traffic flow due to the access to the car park facilities of the Polyclinic. We also observed unauthorised stops for passengers entering and exiting the polyclinic, illegal parking and a general lack of clear signage for road users.

Based on the findings, short-term interventions have been proposed, aimed at simulating tactical and immediate solutions to address the demanding problems on this area. These measures, characterised by relatively low costs and short-term implementation, aim to ensure definite benefits for improving accessibility to POIs with consequent benefits for users.

4.2 Project Scenarios Results

The analysed scenarios have been setup with an "incremental" configuration, with each scenario maintaining the measures adopted in the previous one while introducing new measures. In the following paragraphs, the three proposed scenarios are described, and the results are presented comparing them with the current state of affairs.

Scenario 1

The main objectives of the first intervention in Scenario 1 are to reduce waiting times needed to access parking facilities, to prevent long queues formation and consequently congestion phenomena in the whole area. In addition, the intervention aims to minimise interference between traffic flow entering and exiting the car parks. The first solution (intervention ***a***) involves speeding up the entry procedure to the car parks. Currently, each vehicle entering car parks corresponding to manoeuvres 'B', 'D' and 'G' (Fig. 6) experiences a significant delay. The proposed measure reduces the entry time per individual vehicle from approximately 30 to 25 s, which can be achieved through the the implementation of simple and widely adopted parking management technologies, such as license plate recognition or automatic ticketing systems.

A second modification (intervention ***b***) involves closing access to car park "B", resulting in the redistribution of outflows to the upstream entrance of car park "C". This measure stems from two main observations: the first, already identified during the infield survey phase, concerns the queues generated by the current access system to the car parks, which cause significant slowdowns in through traffic; the second, identified by the simulation, shows that the entrance to car park "B" is placed along a section with a reduced roadway, causing a significant slowdown in vehicle flows and hindering the proper use of the two available lanes.

In brief, the changes proposed in this scenario are as follows:

a. "Reduction in access time to car park facilities"
b. "Deactivated Exit from car park in B"

Scenario 2

The second scenario includes the interventions proposed in the first scenario and, in addition, it involves a change in the location of the entrance to the Policlinico (intervention ***c***), aiming to reduce the volume of traffic on Via Santa Sofia. The aim of this measure is to prevent users from travelling along the entire road in order to access the hospital area.

Currently, a user coming from the south must enter on F and exit on C, driving along a long stretch of Via Santa Sofia. However, in most cases they are forced to re-enter the road network at C and look for parking elsewhere, effectively doubling the number of passages on this road. The proposed intervention is to eliminate the access from F by reversing the traffic flow and consolidating all access points at C. This solution aims to minimize unnecessary trips and reduce congestion on the main arterial road.

In summary, the changes proposed in this scenario are as follows:

a. "Reduction in access time to car park facilities"
b. "Deactivated Exit from car park in B"
c. "Polyclinic internal route changes and consolidation of access points in C"

Scenario 3

The aim of the third scenario is to further reduce the number of vehicles in Via Santa Sofia and to facilitate more efficient access to the various POIs located along the route. To this end, intervention (***d***) has been proposed, which involves extending the shuttle service to improve the connection between the POIs and the "Santa Sofia" park-and-ride.

Currently, a bus line named A-MS is operating, connecting the car park "Santa Sofia" to the metro station "Milo" with a frequency of 5 min, but only during peak hours. In the microsimulation model, an extension of the service to every 5 min was assumed for the whole morning. The expected effect of this measure is a 10% reduction in vehicle flows in Via Santa Sofia, thus contributing to the improvement of accessibility.

In brief, the changes proposed in this scenario are as follows:

a. "Reduction in access time to car park facilities"
b. "Deactivated Exit from car park in B"
c. "Polyclinic internal route changes and consolidation of access points in C"
d. "Increasing the frequency of the A-MS line"

The results of the three scenarios are compared with the current state of affair (i.e. Scenario SoA) and summarized in Table 2.

Analysis of the different scenarios highlights a significant improvement in terms of queue reduction: the first intervention resulted in an improvement of around 70%, the second reached approximately 92%, and the third showed an improvement of about 86%. Travel times also decreased, although this benefit was particularly evident only in the first scenario, with a reduction of 61%.

Table 2. Scenario comparison, LOS, Travel time and Queue Length

Path	LOS S. SoA	LOS S. 1	LOS S. 2	LOS S 3
A-B	F	B	A	A
A-C	F	B	B	B
A-D	F	B	B	B
A-E	F	B	C	B
A-F	F	D		
A-G	F	D	D	C
A-H (BRT1 lane)	F	A	B	B
A-H (inner lane)	F	D	C	B
C-A	F	E		
C-H (outer lane)	F	C		
H (outer lane)-C	F	D	F	F
H (outer lane)-D	F	E	F	D
H (outer lane)-E	F	D	F	D
H (outer lane)-F	F	E		
H (inner lane)-A	D	D	F	E
H (inner lane)-G	F	E	E	E
F – H			B	A

Path	Travel time S. SoA	Travel time S. 1	Travel time S. 2	Travel time S. 3
A (from start of street) - H (inner lane)	7,36 min	2,96 min	2,80 min	2,72 min
A (from start of street) - H (outer lane)	2,70 min	2,87 min	3,41 min	3,06 min

Section	Length of queue S. SoA	Length of queue S. 1	Length of queue S. 2	Length of queue S. 3
1	790 m	429 m	25.93 m	13.95 m
2	524 m	0 m	86.13 m	14.77 m
3	330 m	55 m	33.93 m	41.78 m

5 Conclusions and Future Research

This study proposed and tested a comprehensive methodological approach to support the design and evaluation of targeted interventions aimed at improving traffic conditions and accessibility in complex urban environments. By integrating microsimulation modelling, demand analysis through advanced surveys and sensor data, and the evaluation of alternative intervention scenarios, the methodology allows for a detailed understanding of current dynamics and the potential impacts of low-impact solutions.

The proposed interventions for the analysed case study in the urban area of Catania have been configured as short-term solutions, as they do not require major infrastructural changes. However, to ensure the success of these strategies, a thorough revision of the signage is essential, aimed at directing users towards the Santa Sofia parking lot. In this context, the installation of variable message panels is advisable, as it provides precise and real-time information on parking occupancy. The idea is to allow direct access to the hospital campus only for users with reduced disabilities, while others are guided to the Santa Sofia parking lot, from which the campus can be reached via a shuttle bus service.

These results confirmed that the long access times to the parking lots represent one of the main causes of queues. In particular, the second and third scenarios proposed a complete reorganization of the internal flows within the hospital campus and parking areas, encouraging the use of the park-and-ride facility. Although these measures have been a limited impact on simulations, they significantly improve campus accessibility, especially under conditions of parking saturation. This situation, often not perceived by users waiting to enter, can lead to improper behaviours such as irregular parking along the roadway, which in turn hinders the regular flow of traffic.

The creation of a small-scale digital twin enabled the replication of daily operating conditions, offering a flexible and transferable tool for decision-making. Beyond the specific case of Catania, the proposed methodology is highly replicable and adaptable to a wide range of urban contexts. Thanks to its modular structure and the use of widely available tools, such as microsimulation platforms and sensor-based data collection, it can be applied in different cities to support evidence-based planning and the efficient allocation of resources. Future research will combine macro and micro perspectives, based on macroscopic fundamental diagram theory and urban traffic microcirculation theory, and study an innovative macro traffic control strategy and micro traffic organization method. The evaluation will be conducted through VISSIM dynamic traffic simulation. In this regard, the micro traffic organization method based on the concept of microcirculation can effectively utilize road resources for diversion, significantly improving the service level of intersections and roads in the analysed area.

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