New Smart Mobility Applications: Preliminary Findings on a Pilot Study in the Municipality of Artena

Mauro D'Apuzzo[1], Azzurra Evangelisti[1], Daniela Santilli[1(✉)], Stefano Buzzi[1], Mauro Mazzei[2], and Viviana Bietoni[1]

[1] University of Cassino and Southern Lazio, Via G. Di Biasio 43, 03043 Cassino, Italy
{dapuzzo,daniela.santilli,buzzi}@unicas.it
[2] CNR, Italian National Research Council, Via dei Taurini 19, 00185 Rome, Italy
mauro.mazzei@iasi.cnr.it

Abstract. Whether for work, for leisure or for moving goods necessary for health, people and industry, mobility is a fundamental aspect of economic and social life of each community. Unfortunately, it is not without costs for the society: gas emissions, air, water and noise pollution, road crashes, congestions, are examples which affect health and environment. For these reasons the most severe challenge for the transportation sector is to become more sustainable, resilient and safe. All can be possible only betting on green mobility and cutting-edge digital technologies.

According to this vision, the "Smart Urban Mobility Management" (SUMMa) project has been proposed, with the aim to develop, for the Artena Municipality, new service structures for modernizing and managing transportation systems, by means of digital technologies and 5G communication networks. In particular the proposed digital platform, thanks to enhanced Mobile Broadband, massive Machine Type Communications and Mobile Edge Computing, can support Artificial Intelligence algorithms for recognition image and interpretation of field data, collected by drones or H-D cameras. In real time, Origin-Destination flows, individual trips and environmental data can be update and traffic, congestion and health information can be shared with the citizens.

In this paper, the general architecture of the SUMMa platform has been described and preliminary findings of the pilot project in the Municipality of Artena have been presented.

Keywords: Smart mobility · Smart road · Sustainable mobility · SUMMa project · 5G communication technology · AI technology

1 Introduction

Mobility, today more than ever, is synonymous with freedom, prosperity and health. In fact, comparing the effects suffered by the global economy and by the social and health dynamics, due to the strong reduction or prohibition of free movements (of both people and goods), the COVID-19 pandemic has demonstrated, once again, the crucial

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function of the transport systems for the modern societies. Rather, the need to extend an efficient supply chains not only within single Nations but in a European or World dimension appears clear [1]. Based on this new impulse, all the projects that invest in modernization, efficiency and digitization of the transport activities become essential for Authorities and Municipalities.

The common vision consists to make transportation systems more sustainable, resilient, intermodal, smart and safe. In this direction, European Commission and National Authorities promoted Guidelines, Plans and Strategies also for targeted investments such as deployment of novel and sustainable technologies in transport, use of drones, unmanned aircraft and cutting-edge tools, deployment of the highest performance of digital infrastructure (as 5G) and employment of Artificial Intelligence (AI) for transport automation and intelligent transport system (ITS) [1–3], in order to achieve *Smart Mobility Systems.*

The term *Smart Mobility* has been intrinsically associated with *Smart Cities* because innovative, green, efficient and connected cities can't be achieved without technological, sustainable, safe and digital transportation infrastructures [4–6]. It requires digital platforms and technical infrastructure able to guarantee optimized, diffused, accessible and intermodal mobility solutions and services [7, 8], preferring, where possible, the safeguard of vulnerable users [9]. Several applications are developing within Europe and World context, and in Italy, thanks to the MIT Decree 70/2018 [10] the on-road testing of connected and automatic driving solutions began. In particular, the *Smart Road* concept was introduced as the "road infrastructure where a digital transformation process is carried out aimed at introducing traffic observation and monitoring platforms, data and information processing models, advanced services to infrastructure managers, public administration and road users, in the framework of the creation of a technological ecosystem favorable to interoperability between infrastructures and new generation vehicles" [10].

The present study is carried out in the framework of the "Smart Urban Mobility Management" (SUMMa) National Project, within the Smarter Italy Project [11], with the aim to valorize new digital technologies such as IoT (Internet of Things), AI, Blockchain and the use of 5G communication networks, to improve the competitiveness of the transportation systems through new services for the management and modernization of both urban and rural mobility systems. The Municipality of Artena hosts the SUMMA pilot project.

1.1 Smart Urban Mobility Management (SUMMa) Project

The "Smart Urban Mobility Management" (SUMMa) Project, promoting the Green Economy and Sustainable Mobility, aims the design and development of a telematic platform, fully-integrated on the 5G platform, for the analysis of mobility.

Through the use of highly innovative tools such as drones, H-D cameras, IoT Sensors on 5G network and AI tools, infrastructures, things and people can be connected one each other for the development of an effective model of Smart Mobility with the implementation of vertical services as: *Smart Parking* - monitoring of parking areas and management of free parking spots to guide the users to the parking stall, optimizing search and stay times in traffic; *Environmental Control* - monitoring of air and water

quality in urban environments, and Blockchain certification of the data; *Smart Road Safety* - advanced monitoring of the road arteries for the control of vehicular flows and congestions for the territorial control and *Sustainable Mobility* - provides information to design cycle paths (also useful for a possible subsequent adoption of a bike sharing service) and for the retraining of pedestrian paths. A simplified representation of the SUMMa platform architecture is reported in the Fig. 1.

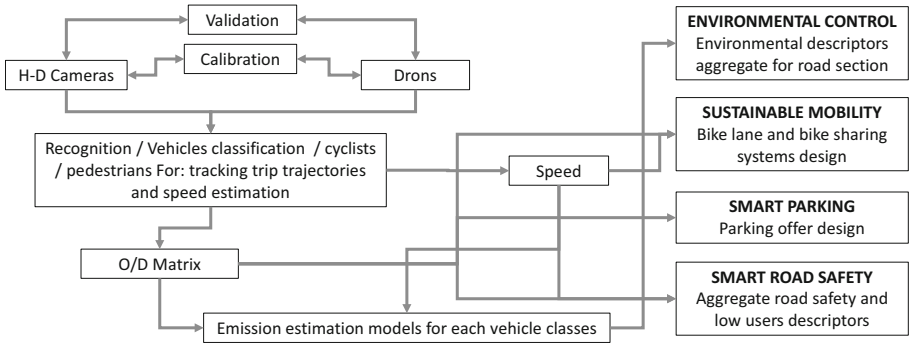

Fig. 1. Simplified SUMMa platform architecture.

These technologies are based on an enhanced and efficient database for collecting and analyzing huge volumes of data (Big data) that the sensors and applied systems make available. For this reason, it will be experimented a simultaneous deployment of enhanced Mobile Broadband (eMBB) connections, massive Machine Type Communications (mMTC) and Ultra-Reliable Low-Latency Communications (URLLC) in a 5G network. The platform, by means of the Blockchain structure which, by the way, guarantees the authenticity of the collected data, will be able to accommodate video analysis services and recognition of critical scenes (i.e. accidents, queues, natural disasters, etc.), integrating video flows from drones and cameras for territorial monitoring. This architecture allows to trace in real time the scenarios relating to the modal distribution of mobility flows in the reference urban context and to monitor the viable arteries to preserve city safety standards.

Therefore, thanks to the real time collected data, within the study area, traffic flows and individual trips will be monitored and, detecting and aggregating the data by time intervals (i.e. peak and off-peak daytime intervals, etc.) and by day types (i.e. working days, holidays, etc.) in real time, update Origin/Destination (O/D) matrices and provide information to authorities and citizens in order to, for example, reduce the time spent on the road by vehicles or to find the parking stall, to optimize the paths favoring the flow of congested areas (also for pedestrians, anti-gatherings, according to policies to combat the spread of Covid 19) and to promote alternative and sustainable mobility modes (as bicycle or walking).

In order to implement statistical models and O/D matrices to adapt the mobility demand to the service offered by the transport system and to optimize the collected traffic data, the mobility in the Artena's territory has to be known, through the development of a Travel Demand Forecasting Model.

2 Travel Demand Forecasting Model

Generally, a travel-demand model can be defined as a mathematical relationship between the travel-demand flows on the one hand, and the transportation network system, on the other hand. The most used traffic prediction model in Transportation Engineering is the Travel Demand Forecasting Model, TDFM [12]. The TDFM, also known as four-step travel demand model, is an ordered system of four sub-models, each of them related to one or more choice dimensions: the traffic emission model, the traffic distribution model, the traffic mode-choice model and the path-choice model (see Fig. 2).

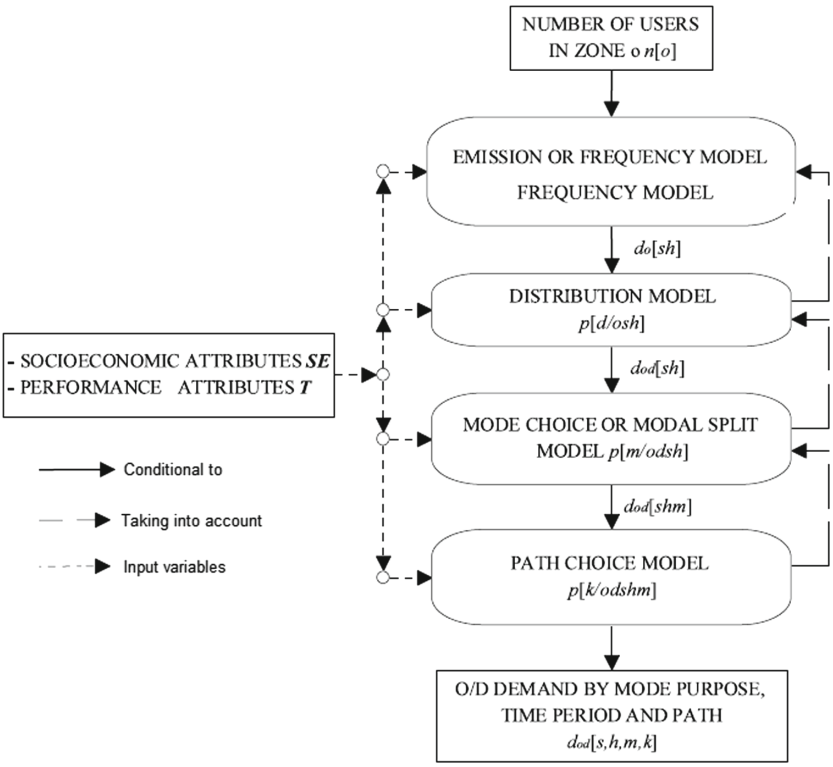

Fig. 2. Four-step trip-based travel-demand model system [12].

It provides, on a specific reference period, all the trips undertaking in a specific analysis area, according to their purpose, time period, origin, destination, path, transport mode, socio-economic role of the user and defining fixed performance attributes (T) of the network system and socio-economic attributes (SE) of the area. The TDFM can be formally expressed by means of the following expression [12]:

$$d^{i}_{od}[s, h, m, k] = d^{i}_{o}[sh](SE, T) \cdot p^{i}[d/osh](SE, T) \cdot p^{i}[m/oshd](SE, T) \cdot p^{i}[k/oshdm](SE, T) \quad (1)$$

where:

d^{i}_{od} [s, h, m, k] is the average number of trips of the class user (cu) i, starting from origin traffic zone o, finishing in the destination traffic zone d, for a specific purpose s, within the time period h, using the transport mode m, and choosing the trip path k;

d_{io} [sh](SE,T) is the average number of trips of the cu i, for purpose s, within the time period h, that starts from o;

p^{i} (d/osh) is the fraction of trips of the cu i, for purpose s, within the time period h, that starts from o and finishes to d;

p^{i} (m/oshd) is the fraction of trips of the cu i, for purpose s, within the time period h, that starts from o and finishes to d, by means of the transport mode m;

p^{i} (k/oshdm) is the fraction of trips of the cu i, for purpose s, within the time period h, with the transport mode m, that starts from o and finishes to d, using the trip path k.

It is worth to be highlighted that, due to specific peculiarities which belong to each activity system and its transportation services and facilities, an ad hoc preliminary evaluation, relating to the identification of relevant spatial dimensions of the transportation network and of spatial characterization of trips, is required.

Generally, it consists into the definition of the study area; the zoning process (subdivision of the defined area into discrete traffic zones with defined socioeconomic characteristics), the identification of the basic network and the development of the O/D matrices [12]. Its application to the Artena's territory has been presented below.

3 Framework of the Study Area

3.1 Framework of the Territory, Infrastructures, Economy and Population of Artena

Artena is an Italian municipality of the metropolitan city of Rome, about 30 km south.

The municipal territory, which extends for about 54.8 km^2, has a morphology characterized by different levels of altitude. The oldest part of Artena, in fact, stands on a hill belonging to the Ernico-Lepino-Ausona ridge and which is between 400 and 600 m above sea level (als). The most recent part, on the other hand, rises on the plain of the Sacco River which stands at altitudes between 200 and 250 m als and surrounds the edge of the ridge on which the ancient part of the city is located.

According to the 15th Census of Population and housing 2011 [13] of the Italian National Institute of Statistics (ISTAT), the Artena's population exceeds 13.660 habitants, considering the resident population 15 years or over, there are: 4913 employed, 825 students, 552 unemployed and 2060 house-workers. Among these, 3642 habitants daily move outside the municipality for work or study reasons.

On the other hand, as far as the economic and productive fabric of the territory of Artena are concerned, according to the 9th Industry, services and non-profit institutions Census 2011 of ISTAT [14], 775 economic units were identified, including private, public and non-profit activities with 2278 employees, 430 volunteers and 33 other-workers categories.

The habited centers, the productive, commercial and services activities are mainly concentrated along the provincial roads, while the remaining part of the territory is

mainly characterized by the presence of agricultural plots. It is therefore possible to identify a more densely populated/commercial area within the municipality of Artena (see Fig. 3).

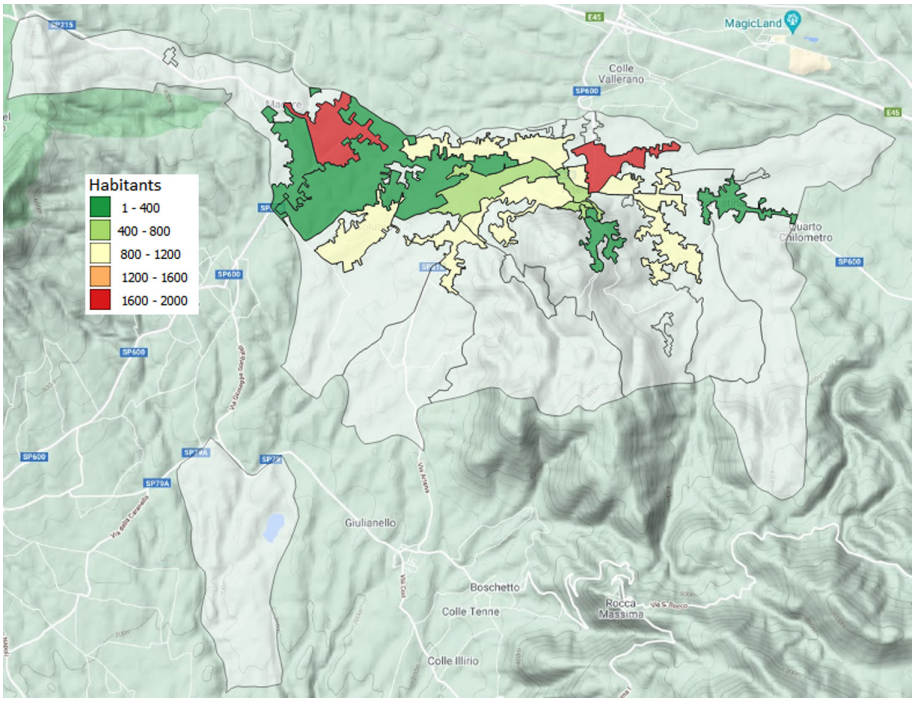

Fig. 3. Population distribution on the territory of Artena [15].

Artena benefits from the presence of several infrastructures, located outside the municipal area, but which strongly affect internal traffic, in fact, to the north is the regional road (SR) 6 Casilina and the A1 Rome-Naples Highway with the "Valmontone" exit about 2 km and the "Colleferro" exit about 8 km from Artena center. To the south is the state road (SS) 7 Appia. The internal penetration network of the Artena territory starting from the municipal border, converges at the foot of the ancient and perched area which is crossed by a single alternating one-way road and is therefore mainly an area intended for pedestrians or two-wheeled vehicles. Finally, the territory of Artena is served to the north, by the Roma Termini - Cassino railway line with the Valmontone and Colleferro stops and to the south by the Roma Termini - Velletri railway line, with relative stop (see Fig. 4).

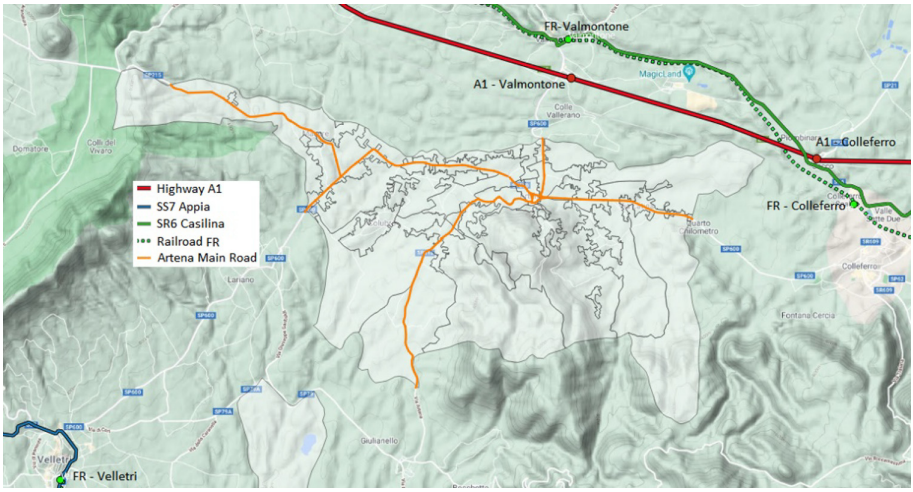

Fig. 4. Main Infrastructures close to the territory of Artena [15].

3.2 Preliminary Traffic Flow Analysis

With the aim to identify an effective zoning, a preliminary analysis of the commuting trips for work and study purposes have been performed, by using the ISTAT open-source database [13]. In particular two different kind of sources data have been used: the *commuting matrix*, which characterizes a generic trip defining Province and Municipality of origin (residence), Gender, Purpose (study or work), Province and Municipality of destination, Mode of transportation, Exit time and Trip duration and *micro-data*, which defines only the geolocation at census-particle level.

According to the well-known Origin/Destination (O/D) matrix structure, the analysis of the commuting trips has been performed for the following groups: internal trips; internal-external exchange trips; external-internal exchange trips and crossing trips.

Artena's Internal Trips: These are all the trips that start and finish within the municipality of Artena, which according to the commuting matrix (municipal level), are 2969 trips per day. Due to the geolocation uncertainty, intrinsic of the micro-data, only 2105 of them can be used for the analysis (equal to 79%, in agreement with 76,57% observed on National scale). In the Fig. 5 a and b, are reported graphical representations of the distribution of emitted trips (census-particle as origin) and attracted (census-particle as destination), respectively.

Artena's Internal-External Exchange Trips: These are all the trips that start from Artena and finish outside the municipal area, which according to the commuting matrix, are 3649 trips per day. In particular, 15 different Provinces attract trips from Artena and more than 98% of the total trips are attracted by the provinces of Rome, Frosinone and Latina. Therefore, taking into account all the municipalities that attract at least 1% of the trips from Artena, 3270 trips per day have been considered (about 89.72%).

In the Fig. 6 is reported the distribution of emitted trips from Artena (census-particle as origin) to the external municipalities.

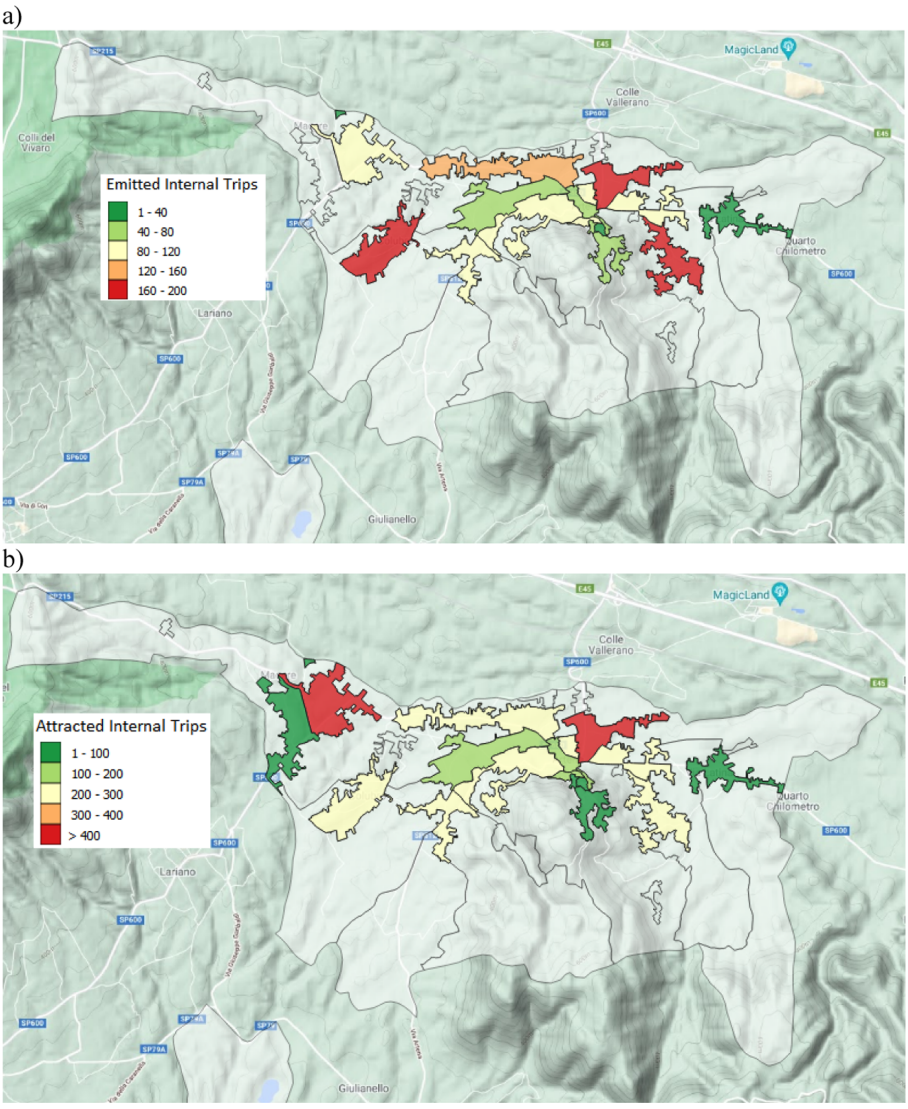

Fig. 5. Distribution of a) Emitted trips (census-particle as origin) and b) Attracted trips (census-particle as destination) [15].

Artena's External-Internal Exchange Trips: These are all the trips that start outside Artena and finish within the municipal area, which according to the commuting matrix, are 946 trips per day. Also in this case more than 99% of the total trips are emitted by the provinces of Rome, Frosinone and Latina. Therefore, taking into account all the municipalities that emit at least 1% of the trips attracted by Artena and summing the geolocation uncertainty, 540 trips per day have been considered (about 57.08%).

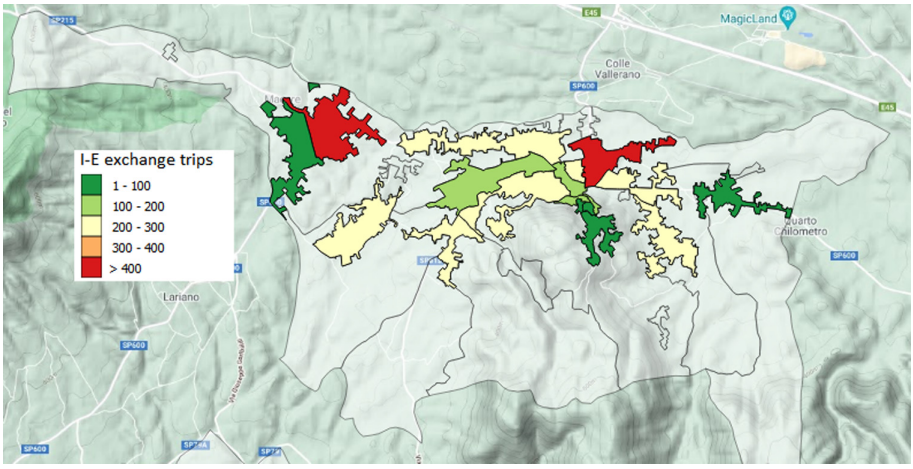

Fig. 6. Distribution of the internal-external exchange trips (census-particle as origin) [15].

In the Fig. 7 is reported the distribution of trips attracted by Artena (census-particle as destination).

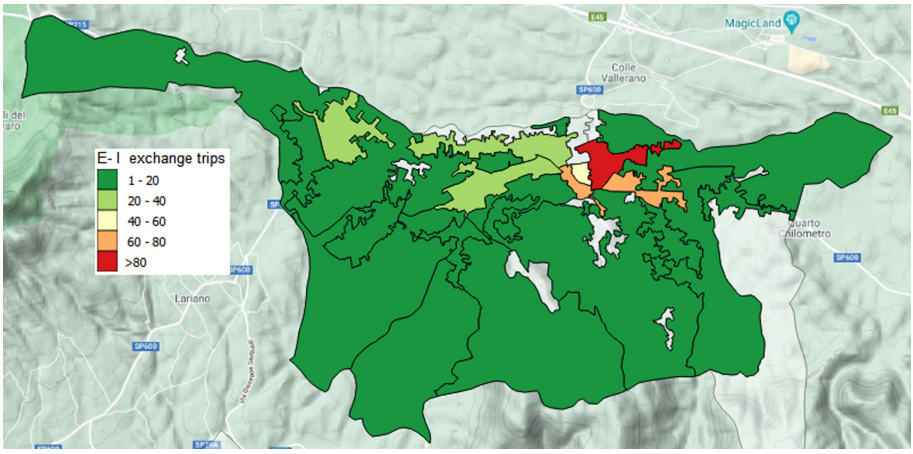

Fig. 7. Distribution of the external-internal exchange trips (census-particle as destination) [15].

Artena's Crossing Trips: These are all the trips that have both their origin and destination external to the Municipal area, but use the transportation system of Artena affecting the internal traffic. In order to describe adequately, albeit approximately, the crossing trips, at least the municipalities adjacent to the territory of Artena have been selected (see Fig. 8) and Rome, Frosinone and Latina as strong attractors within a radius of 50 km area, have been also considered.

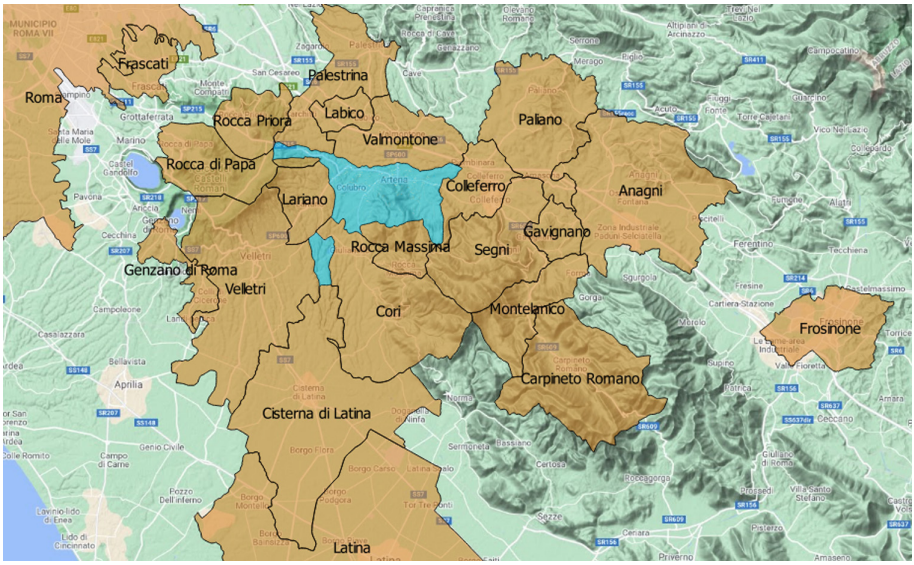

Fig. 8. Position of the Municipalities considered for the crossing trips evaluation [15].

4 Traffic Modeling

4.1 Zoning and Road Network Structure

For this analysis, the study area coincides with the entire municipal territory of Artena. Everything outside the border, called cordon, is external environment and only the interconnections with the study area are taken into account.

Generally, the trips that are carried out in a given area, can start and end in any point of the territory, but to allow the transport system modeling, it is necessary to discretize the study area into traffic zones, characterized by an internal centroid, where it is assumed that all the emitted and attracted trips are located.

As far as the Artena' s territory is concerned, the ISTAT subdivision proposes 38 micro-zones. Taking into account the location of habited zone and productive activities and considering the results obtained by the preliminary trips analysis, a zoning with 11 internal zone and 7 external centroids has been proposed and represented in the Fig. 9.

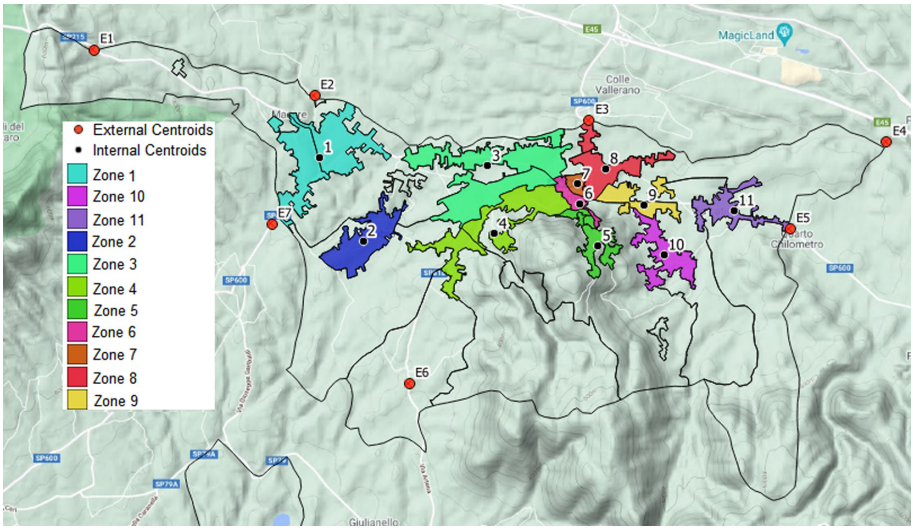

Fig. 9. Proposed zoning of Artena [15].

This simplification is acceptable, in fact, are still considered: 99.7% resident population, 99.8% resident-employed, 92.2% economic activities, 92.5% employees, 92.8% volunteers and 90.9% other-workers category. In the Table 1 the emitted and attracted trips for each traffic zone have been summarized.

Table 1. Emitted, attracted and total trips for each traffic zone.

Zone	Emitted trips	Attracted trips	Total trips
1	499	88	587
2	465	14	479
3	610	213	823
4	652	144	796
5	620	43	663
6	227	234	461
7	358	351	709
8	644	607	1251
9	349	173	522
10	478	31	509
11	2	36	38
%	**99,78**	**88,51**	**96,31**

Finally, the identification of the relevant transportation network of the Artena's territory has been performed and used to model the road network system. Three different level of road category have been identified: State (about 7.5 m of width), municipal (5.5 m) and local roads (3 m) and the representation of the basic network graph can be observed in the Fig. 10.



Fig. 10. Graph of Artena's road network.

4.2 O/D Matrix Evaluation

For the evaluation of the O/D matrixes, based on the proposed zoning, the ISTAT commuting matrix has been used to estimate the fractions of trips distinguishing for mode and exit time (ET) interval. By way of example, in the Table 2 have been summarized the coefficients used for splitting up the total trips reported in the micro data database.

In the absence of traffic counts, in order to develop a traffic daily pattern, it has been assumed that: 1) the morning peak hour matrix is the heavier between the four exit time intervals of the ISTAT commuting matrix; 2) the lunch hour matrix is composed of 100% of trips for study purposes and 50% of work trips of public employees (transposed respect to the morning one); 3) the afternoon hour matrix is composed of 50% of work trips of public employees and 100% of work trips of private (transposed respect to the morning one); 4) the off-peak hour matrix is the 0.05 fraction of the morning peak hour. Where:

- for internal trips and external-internal exchange trips the ratios between public and private employees is assumed equal to Artena's reference 88% private workers 12% public workers [14];
- for internal-external exchange trips and crossing trips, the ratios between public and private employees is evaluated with reference to Rome (the external municipality with the most attraction trips 78.5% private workers 21.5% public workers [14].

Table 2. Coefficients of Modal Partition for micro-data internal trips analysis.

Study purpose				
ET interval	<7:15	7:15 ÷ 8:15	8:15 ÷ 9:15	>9:15
	0,04	0,61	0,34	0,00
Car + motorcycle	0,26	0,44	0,57	0,67
Public transportation	0,51	0,40	0,14	0,00
Train	0,12	0,01	0,00	0,33
Bike	0,00	0,00	0,00	0,00
Walking	0,11	0,15	0,29	0,00
Work purpose				
ET interval	<7:15	7:15 ÷ 8:15	8:15 ÷ 9:15	>9:15
	0,49	0,30	0,15	0,07
Car + motorcycle	0,77	0,69	0,67	0,63
Public transportation	0,06	0,02	0,01	0,05
Train	0,01	0,00	0,00	0,00
Bike	0,00	0,00	0,00	0,00
Walking	0,15	0,28	0,32	0,31
Other	0,01	0,00	0,00	0,01

Finally, to take into account the presence of heavy vehicles and other trips purposes, a rate of 10% and of 30%, have been added, respectively.

The data obtained so far, have been used for the preliminary flow evaluation and the results have been reported below.

5 Preliminary Results: Traffic Flows Evaluation

In order to design and apply the better smart traffic strategies for Artena municipality, the development of a complete traffic model of the road network have been performed. Traffic data obtained by the ISTAT open-source database have been used, waiting for more recent and complete traffic count data on the Artena territory, and the traffic assignment has been performed by User Equilibrium method. The preliminary results have been reported below.

By way of example, the traffic flow distribution for the car and motorcycle mode, for both morning and afternoon peak hour matrices have been reported in the Fig. 11a) and b), respectively. As it is possible to see, the internal penetration road infrastructures of Artena (see Fig. 4) are the busiest links of the Municipality, due to the prominent crossing and

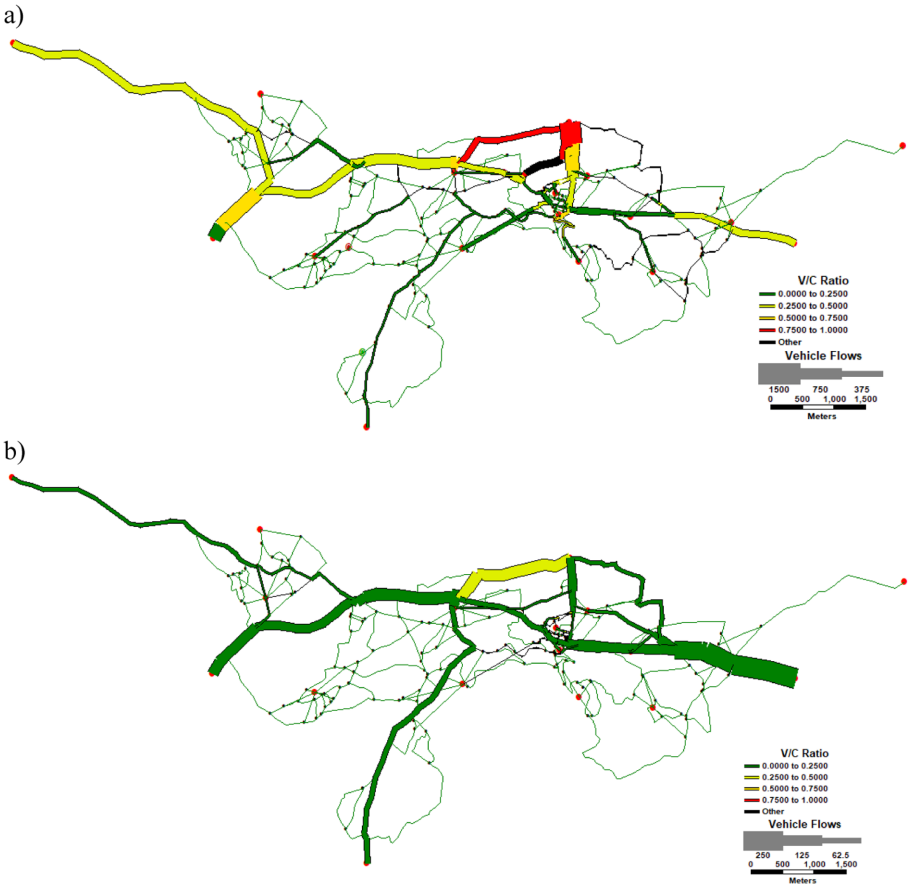

Fig. 11. Car and motorcycle mode traffic flow distribution for a) morning peak hour matrix and b) afternoon hour matrix.

exchange traffic, respect to the internal trips, in fact it is close to an important motorway tollbooth (which connect to main cities like Rome and Frosinone) and to three train stations, for these reasons its territory is therefore also crossed by people who reside in other municipalities, intent to take the motorway or the train.

These preliminary observations have to be validated by the traffic counts and the traffic model have to be calibrated.

6 Conclusion

This paper presents preliminary finding related to the SUMMa Project development, promoted within the Smarter Italy Project. The pilot project took place into Artena Municipality and involved the design and development of a digital platform system for the mobility analysis by means of advanced sensors, drones and cameras that exploit specific AI algorithms and 5G communication infrastructures.

With the aim of optimizing the use of the mobility data that will be made available by the use of the new technologies envisaged by the project, the Travel Demand Forecasting Model of Artena was developed.

The model developed so far, which requires the calibration phase from the traffic counts that will become available, shows that the city of Artena is characterized by a relevant crossing traffic. Instead, the traffic that originates and ends in Artena is lower and would not generate, on its own, reasons for congestion in the area. If these observations will be confirmed by the traffic counts, targeted projects could be design to guarantee traffic fluidification by minimizing crossings and traffic light intersections, and avoiding paths close to downtown activities (schools and offices). The model represents the basis on which the new platform will implement the O/D matrices, updated in real time, and elaborate the best mobility proposal in terms of reducing congestion, emissions and time lost for traveling or searching for parking. The information content will be available to authorities and citizens, to have the best possible experience of smart and sustainable mobility.

As shown in the paper, a depth analysis of the territory and the economy of the study area is needed due to the particularities that characterize each municipality, city or metropolis. It means that the results are specific of the analyzed area and are not applicable without the necessary adaptations. In the same time the presented approach is worldwide suitable because is based on a general and replicable framework and can be used as a guide for the local Authorities intent to design and implement mobility smart applications.

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