Innovative Transport Systems to Promote Sustainable Mobility: Developing the Model Architecture of a Traffic Control and Supervisor System

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Abstract. In the last decades, a big effort has been made in terms of research, strategies and initiatives to boost new forms of sustainable urban mobility, in order to reduce the externalities associated with the transport sector. While the European Commission emphasizes integrated planning at all mobility levels, on the other hand it recognizes that is equally important to make technologically modern mobility system, in order to maximize its efficiency. With regard to this technological modernization, the Intelligent Transport Systems (ITS) are considered as a tool, that to date more than any other, it allows us to manage a "smart" mobility.

Based on this premise, this work concerns the development of a methodological approach to implement a traffic control and supervisor system with related infomobility services. It is identified the conceptual model that represents the basis of the system's architecture, in order to define a set of required services, functional relationships and specific characteristics acknowledged from stakeholders' needs, which will be involved by the system.

This approach is applied to a case study in the urban area of Catania (Italy), through the implementation of a traffic monitoring, estimation and short-term forecasting system, equipped with radar sensor and a central control station for traffic data elaborations.

The obtained results should concur to increase the knowledge of the actual dynamic of road traffic in urban areas, to monitor the reliability of the transport system and to obtain useful data and information that contribute to a more efficient and optimal control of mobility system.

Keywords: Intelligent Transport Systems (ITS) · Smart cities
Smart mobility · Road urban transport network
Dynamic Traffic Assignment (DTA)

O. Gervasi et al. (Eds.): ICCSA 2018, LNCS 10962, pp. 622–638, 2018.
https://doi.org/10.1007/978-3-319-95168-3_42

1 Introduction

Transport has become fundamental to the everyday functioning of society and the economy. Yet the reliance on motorized transport as an everyday function is a substantive contributor to air pollution, climate change and traffic congestion (Chapman 2007), which represent critical issues in urban areas (OECD 2012).

In this context, cities have a key role in fighting against these externalities and the deployment of new intelligent technologies is seen as key factor in decreasing greenhouse gas emissions and improving energy efficiency of cities. These technologies need to be smart, lean, integrated, cost-efficient and resource-efficient, and they should have an impact not only on environmental sustainability targets but also on citizens' wellbeing and financial sustainability (Ahvenniemi et al. 2017). Therefore, it is necessary to promote the development of cities that are not only sustainable but also "smart". In recent years, there has been a shift in cities striving for smart city targets instead of sustainability goals (Marsal-Llacuna et al. 2015). However, these are interconnected and often smart cities share similar goals as sustainable cities.

A smart city is a city that works in an intelligent and sustainable way, integrating all their services and infrastructures and services as a whole, using intelligent devices to control and monitoring to ensure sustainability and efficiency (Hancke et al. 2013). Thus, Smart Cities can be considered a key to a sustainable urban development. A common understanding, also shared by the European Commission, is that diverse technologies help in achieving sustainability in smart cities (European Commission 2012). Accordingly, smart cities and communities focus on the intersection between energy, transport and Information and Communication Technologies (ICT), which are also the fields that have received most of the EU's public smart cities related funding (under the Horizon 2020 program "smart cities and communities"). In fact, ICT have recently been applied in programmes to support sustainable urban development. In particular, initiatives in the transportation sector aim at improving the safety, efficiency and sustainability of large cities. Intelligent transportation systems (ITS) are among the first applications in this sector. ITS are, generally speaking, combinations of technologies for increasing efficiency in vehicular traffic and they strongly depend on information, and more specifically, on data about the traffic or the mobility of vehicles (Torrisi 2017). An ITS (or Smart Traffic System) able to monitor, predict and, ideally, manage traffic flows, is an essential component inside the philosophy of a smart city. An optimal traffic management system would shorten the users' displacement times (both in private and public transport). Therefore, this system would lead to a save in energy consumption and also in generated emissions (Arnott 1994; Rahane and Saharkar 2014). In summation, different elements in a city, such as vehicles and people, can be detected by a number of sensors to obtain a wide quantity of data. These data can be the base to extract knowledge. Understanding those patterns that guide the inhabitants of an intelligent city is a compelling research area and it is the field of intelligent transport, which is the most important one for this work.

Starting from these remarks, this paper aims to describe a methodological approach for implementing a traffic control and supervisor system with related infomobility services. An application of this methodology is presented through the case study of

Catania, by analyzing the implementation of the traffic monitoring, estimation and short-term forecasting system, equipped with radar sensor and a central control station for traffic data elaborations.

The reminder of the paper is as follow. After an introduction about the application of telematics in the transport sector and the role of ITS in Smart Cities, the second section discusses the methodological approach to develop the system's architecture. The third section presents the case study and describes the functional components and the operating functioning of the implemented system. The last section concludes the paper by summarizing the main findings and directions for further development of the research.

2 Methodological Approach for the Development of the ITS System Architecture

The methodological approach concerns the identification and the development of the model architecture of a traffic control and supervisor system with related infomobility services, hereinafter referred to as *ITS system*.

The telematic architecture of this ITS system is based on relevant components for pursuing specific objectives relating to "smart mobility". This architecture is realized starting from a set of requirements (User Needs), which represent the stakeholders needs that interact with the transport system. It is a structure that identifies the involved subjects, all the requested services, the functions, the specific characteristics and the subsisting relationships between these elements to support mobility.

The basic structure of the architecture consists essentially of five elements:

– a conceptual model;
– a logical/functional architecture;
– a physical architecture;
– a communication architecture;
– an organizational architecture.

This proposed structure can be considered shareable and applicable to all ITS systems' architectures and it can be developed by favoring specific functions rather than others. Specifically, as stated in the introduction, this study focuses on the implementation of a real-time traffic monitoring and control center with related info-mobility services. In this way, the claimed requirements and to frame all the services and functionalities of the system have been identified.

2.1 Conceptual Model

The basis for developing the ITS system architecture is the definition of the conceptual model. First, starting from the analysis of the study area, with reference to the transport system and the actual state related of private mobility, the *User Needs* or *User Requirements* can be identified. Through these needs, the functions to be integrated in the system are determined, as listed below:

– acquisition of real-time traffic data in field, from fixed sensors and Floating Car Data (FCD);
– real-time simulation of the entire analyzed transport network, including not directly monitored links;
– decision-making support for the identification and implementation of traffic control and management policies;
– infomobility services using real-time information systems such as variable message signs (VMS), web portal and multimodal dynamic search-path.

This first phase proves to be very useful for the identification of the general purposes for which the system will be implemented.

Then, it is necessary to evaluate the connections that this system has with the external environment. In this regard, the so-called "terminators" have been identified. This term indicates the boundaries of the system, highlighting what the external environment operates to the system and what it may need from it. Therefore, a terminator can be represented by a person or a physical entity through which obtain the necessary information and useful data.

In the case of the ITS system, terminators are represented by the components of the mobility system – i.e. infrastructure, vehicles, users and environment - interacting with each other. The system boundary has been established using the context diagram shown in Fig. 1, representing the relationship between the system and the parts of the external environment with which it interacts.

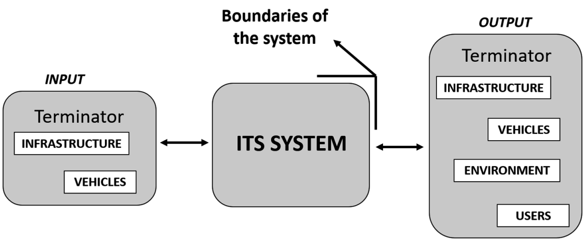

Fig. 1. Context diagram of the ITS system

Considering, for example, the terminator "vehicle", there are two relationships: the "From Vehicle" relationship and the "To Vehicle" relationship (Fig. 2).

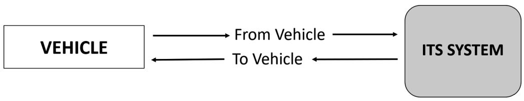

Fig. 2. Relationship vehicle – ITS system

"From Vehicle" relationship, from the terminator "vehicle" to the ITS System, indicates a flow of data containing information about tracked vehicles through sensors inside the vehicle itself; therefore, the transmission is from vehicles to the system, i.e.

from the external environment to the System. “To Vehicle” relationship, from the System to the terminator “vehicle”, indicates a flow of data sent by the system to the vehicle, i.e. for managing the road network; therefore, in this case the information is transmitted by the System to the external environment.

Subsequently, the logical-functional architecture, the physical architecture and the communication architecture will be analyzed.

2.2 Logical-Functional Architecture

The logical-functional architecture represents the connections between the terminators and the functions: it is a block diagram that allows to identify the necessary data store and the logical flows to achieve the prefixed user requirements (see Fig. 3).

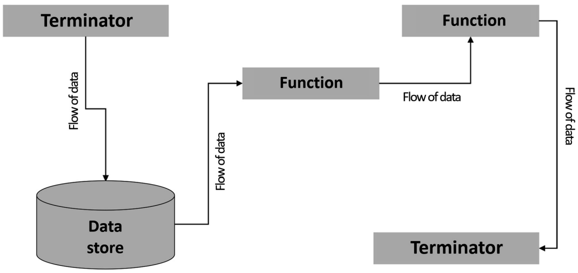

Fig. 3. Simplified model of the logical-functional architecture

The steps to define this architecture for the ITS system are the following:

- identification of logical flows and data stores;
- identification of the necessary functions to satisfy the requirements defined by operators and users.

To develop and implement the ITS system, the functions have been defined and grouped by functional areas, along with the necessary logical flows of data for providing required services. Therefore, starting from the selected functions, the logical flows and the data stores of the system have been identified.

The defined logical-functional architecture of the ITS system has a cyclic structure, where the initial and the final terminator coincide. This unique terminator is represented by the external environment, within the components - i.e. traffic, infrastructure, vehicle, users and environment - interact with each other. Considering the complexity of the ITS system to be implemented, the multiplicity of associated functions has been grouped by functional areas, thus identifying 3 functions, with related sub-function, as summarized in Table 1.

Particularly, the F2.1 sub-function, through the traffic operation centre enables to remotely manage and monitor the installed devices, to simulate real-time traffic estimation and forecasting, considering the effect of any anomalous events, and to create a historical database of traffic data. The F2.3 sub-function provides for environmental monitoring with mapping of pollutant emissions (CO, NOx, HC, CO2, PM, FC) for each link of the traffic network, with a re-calculation procedure at each simulation.

With reference to the F3.1 sub-function, it is characterized by a web portal to provide real-time information to users on the current and future traffic conditions and on the eventual occurrence of anomalous events, such as maintenance works, queues, accidents, etc. Furthermore, it serves to improve the knowledge of the accessibility levels to specific areas and to give information about POI (Point of Interest). Moreover, the dynamic multimodal search-path (F3.2 sub-function) is able to perform a dynamic calculation of the minimum path (which does not necessarily coincide with the shortest one), with travel times and variable costs over time. It allows to make multi-modal transport choices (i.e. car, car-pooling, motorcycle, bus, bicycle, pedestrian) and to adopt intermodal solutions exploiting any feasible exchange between the different transport modes. Finally, the F3.3 sub-function communicates dynamic information related to traffic conditions or eventual management strategies through variables message signs visible to users.

Table 1. Functions and sub-function of the logical-functional architecture of the ITS system

Function	Functional area	Sub-function
F1	Data monitoring	F1.1 – Traffic monitoring through fixed radar sensors
		F1.2 – Traffic monitoring through FCD
F2	Traffic management	F2.1 – Traffic operation centre
		F2.2 – Scenarios simulation and emergencies management
		F2.3 – Environmental monitoring with emissions mapping
		F2.4 – Vehicles routing with VMS
		F2.5 – Access regulation and restricted traffic areas
F3	Infomobility	F3.1 – Web portal with real-time information
		F3.2 – Dynamic multimodal search-path
		F3.3 – Dynamic information with VMS

In addition, to finalize the logical-functional architecture, two different data stores have been identified, which are characterized by a continuous real-time data transmission (Fig. 4).

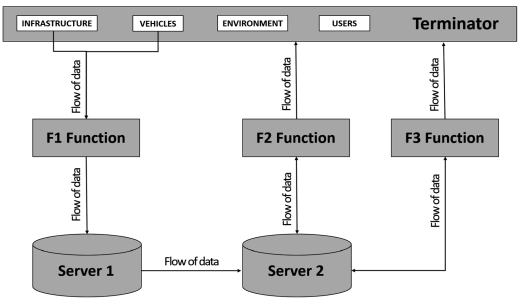

Fig. 4. Logical-functional architecture of the ITS system

The operating cycle of this architecture starts from the terminator. More specifically, from its two components – *infrastructure* and *vehicles* –, a flow of data is originated and attracted by the F1 function of data monitoring. The detected data flow is conveyed within the first data store (identified with *Server 1*), which transfers these data in real-time to the second data store (identified with *Server 2*).

At this point, an exchange data stream is generated between server 2 and the two functions F2 and F3. In this way, the traffic management function F2 has available data to simulate traffic estimates and forecasts, as well as to estimate the associated pollutant emissions. These results are helpful to provide a decision-making support during the planning phase, also allowing to identify several management strategies. Instead, the infomobility function F3 receives a flow of data that can support users to make optimized and intelligent mobility choices. Then, the operating cycle is closed.

2.3 Physical Architecture

This architecture allows the identification of a "physical diagram", which provides the physical location of the functional blocks defined by the logical architecture. Therefore, it allows to move from the functional aspect (theoretical) to the real system (practical).

The previously identified functions can be grouped according to different criteria, such as:

- operational, functional and organizational homogeneity of functions: by grouping together the functions that contribute to the same "macro service" (i.e. to the same higher-level function). In a similar way, the same reasoning can be made with respect to the competence roles, grouping all functions that are under the same responsibility;
- optimization of the exchange information flows: by grouping together the functions to minimize the exchange of data flow; in this way, considering that for each group corresponds a different physical state, the number of communication interfaces is reduced;
- operational effectiveness: by grouping the functions based on the location of processing, storage, management and implementation devices.

Accordingly, each physical location is a sub-system that can contain one or more functions (Fig. 5).

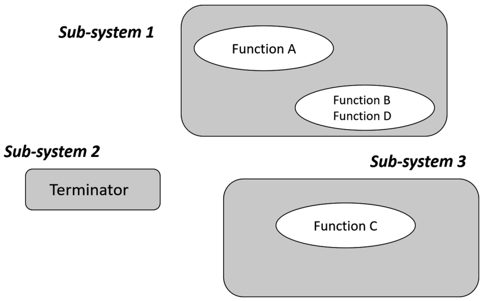

Fig. 5. Simplified model of the physical architecture

The steps to define this architecture for the ITS system are the following:

– identification of the “physical diagram”;
– quantification of macro-flows of data and eventual grouping of functions;
– assignment of logical architecture’s functions to the “sites”;
– analysis of communication requirements;
– definition of the communication interfaces between the sites.

The identification of sites may concern different physical locations, as indicated in Table 2.

Table 2. Physical locations for sites’ identification

Site definition	Location
O = Operator	Physical location of technical-operative offices, IT devices and the company staff that provide services (provider-operator)
INF = Infrastructure	Physical location coincident with the transport infrastructure and services provided with front-end communication devices (roadside)
MC = Management company	Physical location of technical-operative offices, IT devices and the company staff responsible for the operational management of services
PC = Planning company	Physical location of technical-operative offices, IT devices and the company staff responsible for planning offered services and new services
MO = Monitoring organization	Physical location of technical-operative offices, IT devices and the company staff responsible for the control management of services
TL = Transport organizer and logistic cycle	Physical location of transport organizer and logistic cycle offices
U = User	Physical location where user benefits from the service, different from the physical location in which the service is performed or provided
VE = Vehicle	Vehicle to perform the transport of people or goods, through/in which services are provided using communication and user interface devices
FO = Financial organization	Physical location of technical-operative offices, IT devices and the company staff responsible for financial services
MP = Multimodal platform	Physical area for transport modal exchange and related services for management and control of logistic operations

In the case of the ITS system, four physical sites have been identified, respectively named sub-systems 1, 2, 3 and 4, as shown in Fig. 6.

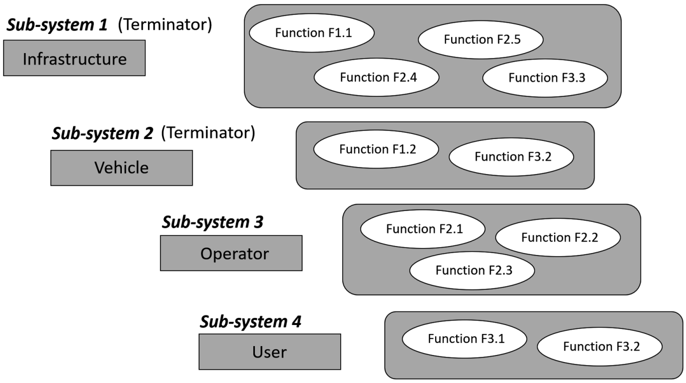

Fig. 6. Physical architecture of the ITS system

The sub-system 1 is constituted by the transport infrastructure, where the peripheral level of the ITS system is installed. More specifically, the radar sensors for traffic flow monitoring (function F1.1) and the variable message signs for vehicle routing (function F2.4), traffic regulation (function F2.5) and users' dynamic information (function F3.3). The subsystem 2 is represented by the vehicle. This physical site includes the functions of traffic monitoring through mobile sensors (function F1.2) and users' dynamic information through the installation of appropriate devices on board (function 3.2). The sub-system 3 is represented by the operator site (for this study the University transport laboratory), where hardware and software of the central system have been implemented for the remote management of devices and data processing. Therefore, it is possible to carry out traffic management functions, i.e. traffic monitoring, estimation and forecasting (function F2.1), scenarios simulation and emergencies management (function F2.2) and environmental monitoring (F2.3). Finally, the subsystem 4 is identified by the user, to whom real-time information services (function F3.1) and dynamic routing (function F3.2) are provided.

2.4 Communication Architecture

The potential technologies and communication networks applicable between physical sites can be represented by multiple solutions: fixed networks, mobile networks, radio-mobile networks, electronic data exchange, traffic data collection and automatic classification, territorial information systems. In the case of the ITS system, 5 communication interfaces have been identified (Fig. 7).

The two sub-systems belonging to the terminator, i.e. the Infrastructure and the Vehicle, they interface with the sub-system 3, represented by the Operator, through two interfaces, which are indicated with INT_INF_O and INT_VE_O. For sub-system 3 and sub-system 4, there is a communication interface between the Operator and the User, indicated with the following nomenclature INT_O_U. Finally, from sub-system 4 there are two further interfaces to connect with the terminator, the interface INT_U_INF with sub-system 1 and the interface INT_U_VE with sub-system 2, as shown in Fig. 8.

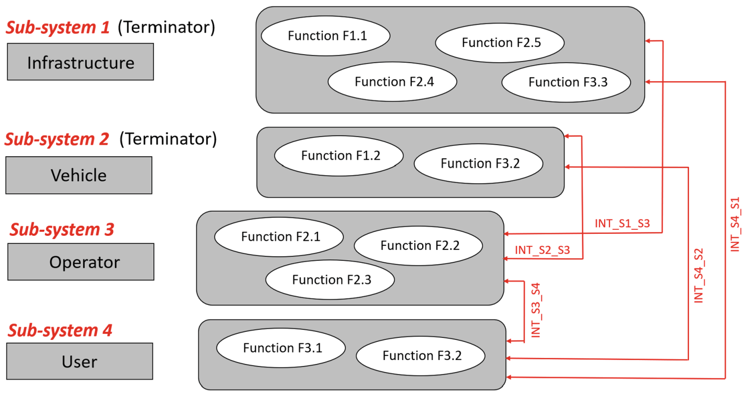

Fig. 7. Communication architecture of the ITS system

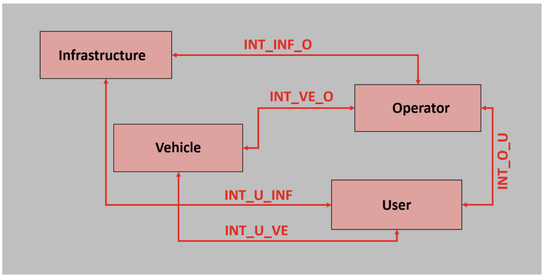

Fig. 8. Interfaces' nomenclature of the ITS system

These interfaces make use of mobile network technologies. Specifically, monitored traffic data are transmitted in real-time to the central system via GPRS (General Packet Radio Service) wireless network. This communication makes it possible to remotely manage the installed devices. Moreover, the continuous transmission of data allows to perform real-time simulations, consistently correcting the estimates and forecasts. Then, the data exchange with servers, by using the DATEX protocol, it allows to use the data from the control centre to manage the infrastructure and to provide real-time users' information.

2.5 Organizing Architecture

The interoperability of the systems is represented not only by the integration of the technologies but also by the agreement between the actors involved by the system. Therefore, it is necessary to design an organizing architecture, making actors work together, thus guaranteeing a more efficient and complete service.

In this regard, a first design of all the high-level processes/functions has been identified. The *macro-process* shown in Fig. 9 represents the formalization of the fundamental steps performed for the implementation of the ITS system and the use of the services associated with it. The activities (value activities) of the macro-process are the following: monitoring and data acquisition; data processing; road network management; predisposition of infomobility services and finally their provision.

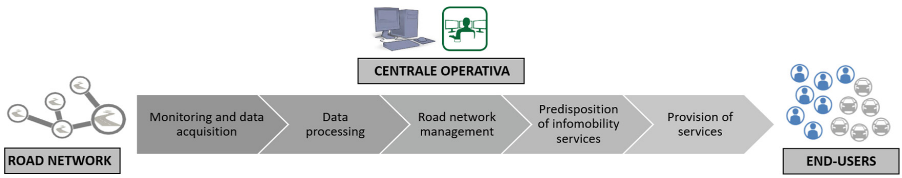

Fig. 9. Macro-process of the ITS system

Subsequently, after the identification of the macroprocess, to structure the organizing architecture of the ITS system, the following activities have been performed:

– identification of activities and responsibilities for each role;
– assignment of professional (economic, political, legal and technological) skills and workforce for each role;
– identification of homogeneous activities groups in order to define involved roles to provide services.

The involved subjects by the implementation of the system and associated services have been considered: public authorities, infrastructure managers, management companies, production companies and end-users. The responsibilities have been identified for each subject: institutional - for the definition of the regulatory/procedural framework related to services; managerial - in terms of correct management to determine the expected value of the system -; commercial - in order to provide the required services congruent to the project and to user expectations; and finally operational - in terms of services provision in line with the levels of service and quality determined by the contract.

This organizational architecture offers a methodological approach to read the services and functionalities defined by the logical architecture, with a view to business and value creation.

3 Case Study: The Traffic Control and SuperVisor System of Catania

3.1 Territorial Framework and Analyzed Network

Catania is a city of about 300.000 inhabitants and it is located in the eastern part of Sicily (see Fig. 10); it has an area of about 183 km^2 and a population density of 1.754,54 inhabitants/km^2. It's part of a greater Metropolitan Area (750.000 inhabitants), which includes the main municipality and 26 surrounding urban centers, some of which constitute a whole urban fabric with Catania (Ignaccolo et al. 2017).

Fig. 10. Catania (source: Catania map – Satellite Images of Catania, available at http://www.maplandia.com/italy/sicilia/catania/catania/)

The main city contains most of the working activities, mixed with residential areas, with a high commuting phenomenon and this has led to a heightened inclination to private mobility with the direct consequence of traffic congestion that greatly affects the network reliability (Torrisi et al. 2017a). According to this vision, the conditions of urban mobility in Catania could benefit from the valuable contribution given by the application of ITS technologies.

Although the Municipality of Catania has not yet created the Urban Mobility Center (the realization of this action is expected in the short term thanks to funding for metropolitan cities destined for the “Infomobility” action), the Department of Civil and Architecture Engineering of Catania’s University has already implemented a mobile ITS laboratory. It allows to know in real-time the traffic flows circulating on the network and simulate the occurrence of anomalous events (i.e. road maintenance, queues, accidents), with an assignment traffic simulation model (Gentile 2011), and the integration of real time traffic data through the “rolling horizon” technique, as proposed by Mahmassani (2001). A system with these characteristics makes it possible to achieve a proactive management of mobility, considering not only the ordinary conditions of the network, but also unexpected situations.

The study area for this research is broadly represented by the white coloured portion of the territory, whereas the grey portion identifies the neighboring municipalities, which are not included, as shown in Fig. 11 (Torrisi et al. 2016).

It coincides with the boundaries of the urban area of Catania and, therefore, the involved subjects to obtain the authorization for implementing this system have been the municipality of Catania and the Office for public street lighting (for sensors’ installation). Furthermore, a part of the network involved the ANAS (Azienda Nazionale Autonoma delle Strade).

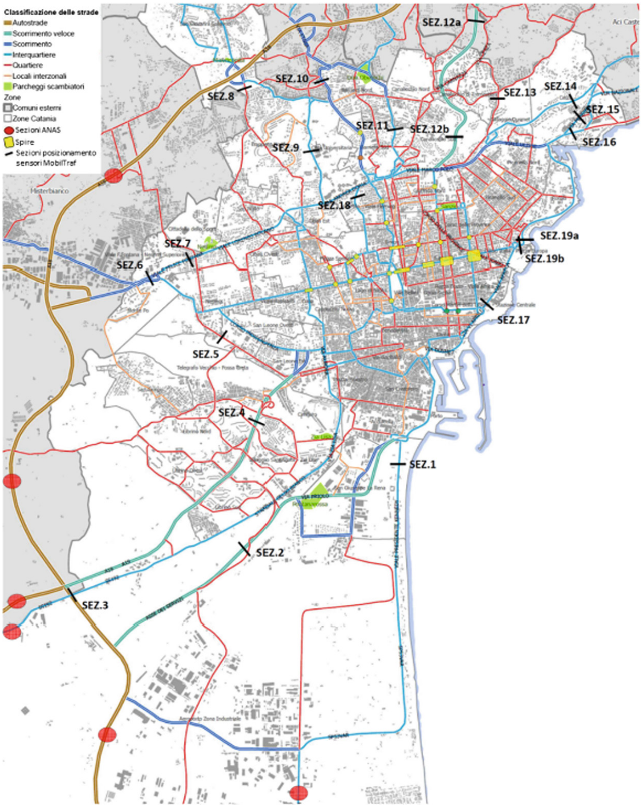

Fig. 11. Study area and monitoring sections

3.2 Functional Components of the System

The implemented traffic control and supervisor system in the urban area of Catania consists of:

– a set of traffic sensors, to measure in real-time traffic flows and to detect the vehicle fleet composition;
– several variable message signs to supply road users with real time information;
– a software for monitoring and managing the installed devices;
– a software for traffic estimation and prediction on-line, combining the dynamic assignment with traffic measures and events in real time;
– a dynamic intermodal and multimodal search path, able to determine the minimum path of transport networks with travel time and costs variable functions over time, taking into account the real-time conditions and the future conditions of transport network;
– a web portal to provide real-time information to users on the current and future traffic conditions and on the eventual occurrence of anomalous events.

These components are organized into three levels: a peripheral and a central level, connected by a communication level, as represented in Fig. 12:

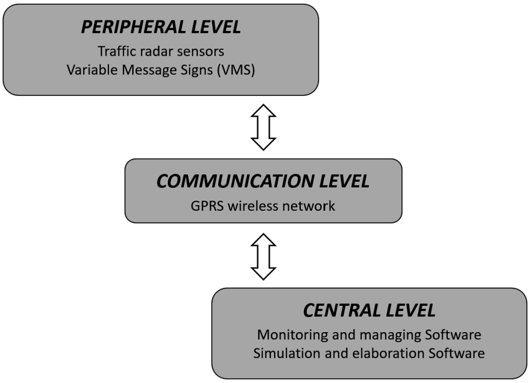

Fig. 12. Organization level of the ITS system

The *peripheral level* is constituting by the traffic monitoring system realized with the radar sensor installed on the road infrastructure and by the VMSs to provide real-time users' information.

The *communication level* is characterized by the GPRS wireless network able to connect the devices, i.e. radar sensors and VMSs with the central system.

The *central level*, installed on high performance server units, is made up of a control and management software, which allows to remotely control and manage in real time the devices, and an elaboration and simulation software, to process collected data, propagating them on the network in order to estimate and forecast traffic flows of each link of the network, even if not directly monitored (more detail can be found in Torrisi et al. 2017b).

Therefore, the absolute advantage of this system is given by the real-time collection and data processing, and also by their elaboration to provide on-line services. Some results related to the implementation of such system have already been obtained: in particular, the real-time quantifying of traffic inflows and outflows by detecting vehicles in 19 monitoring sections located along an ideal cordon that surrounds the urban area of Catania. These data are transmitted in real-time to the control center for their processing in order to obtain traffic simulations extended to the entire transport network. Through these elaborations, it has been possible to carry out studies of the transport network at different levels of analysis (link, path, network) with reference to aspects relating to travel time reliability (Torrisi et al. 2017a) and network capacity (Torrisi et al. 2017b).

3.3 Operating Functioning of the System

The operating functioning of the ITS system is characterized by three phases, which are well schematized in Fig. 13:

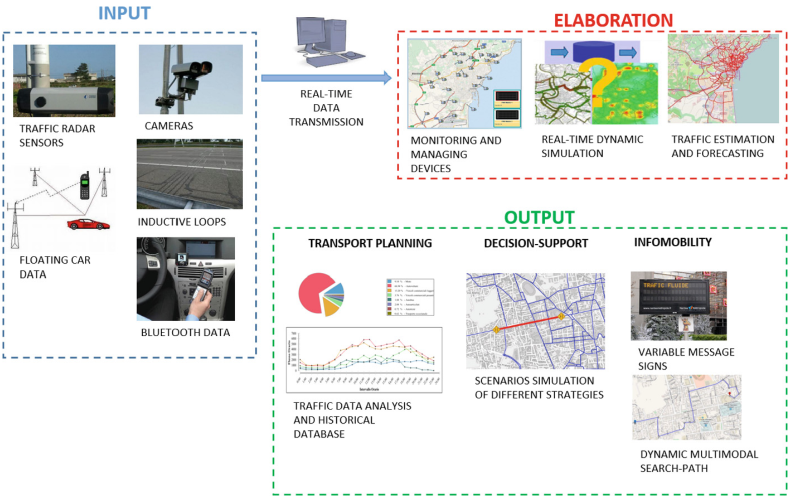

Fig. 13. Operating functioning phases of the ITS system

- Input: the input systems (radar sensors, cameras, inductive loops, floating car data and bluetooth data, etc.) detect traffic data that are transmitted in real-time to the elaboration system;
- Elaboration: is realized by using software that simulate actual and future traffic conditions, based on input data and historical databases;
- Output: simulated data are used to provide decision-making support, both in planning and management transport process. In addition, they provide information to vehicles and drivers and/or actively intervene on traffic regulation and transport network operation.

It is possible to assert that the positive aspect of this system is the ability to work with data coming from various available sources. This feature is very important, as characteristic of interoperability of the system.

4 Conclusions

Nowadays, the transformation of any city into a Smart City, with better performance, i.e. saving energy, citizen's time, resources, costs, is a process that must be supported by powerful and reliable technologies, methods and systems. To this aim, a mobility monitoring system is one of the most useful, since the data which provides can be used to enhance several services in the city.

Owing to real-time communication capabilities, transport systems became capable of acting efficiently based on real-time data. In this context, ITS play an important role in shaping the future ways of mobility and the transport sector. Indeed, ITS convey information regarding congestion level of streets, alternative routes, alternative transportation mediums, etc. to passengers. Moreover, safety and security measures for passengers and pedestrians are enforced in smart transportation systems together with performance improvement. In summary, integrating ITS into smart cities improve operational efficiency of cities, while optimizing time, cost, reliability, and safety of city transportation.

The proposed research moves in this direction, concerning the development of a methodological approach to implement a traffic control and supervisor system with related infomobility services. The first step of this research was to identify the conceptual model that represents the basis of the system's architecture. Afterwards, it was applied the described approach in the urban area of Catania, through the implementation of a traffic monitoring, estimation and short-term forecasting system and related infomobility services.

It is possible to state that the availability of such a typology of architecture provides benefits such as:

– design a system able to meet the claimed requirements;
– correlate these requirements with services and functionalities of the system, guaranteeing the traceability in a project;
– facilitate the disposal of existing redundancies and simplify the provided services and functions, ensuring the consistency of information;
– allow the design of systems with a high level of technological independence;
– simplify the implementation and management of the system;
– support a schematic representation shared by all the involved subjects through the design of an integrated system with standard interfaces between components.

Moreover, through the application of the methodology to the case study of Catania, this paper has revealed that the proposed structure can be considered shareable and applicable to all ITS systems' architectures and it can be developed and implemented by favoring specific functions rather than others.

Further research will be conducted in this direction, i.e. through the spatial extension of the system and its evolutionary maintenance, to improve its current capabilities and add new functions.

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