LIFE ENV 389

INTEGREEN

Action 2: Requirements

D.2.1.1

Supervisor Centre components requirements

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Project Associated Beneficiary n.2	TIS innovation park (TIS)
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1 Introduction

1.1 Purpose of the document

The main objective of Action n.2 is to define the requirements of the components and sub-components that are part of the proposed INTEGREEN system architecture (Figure 1).

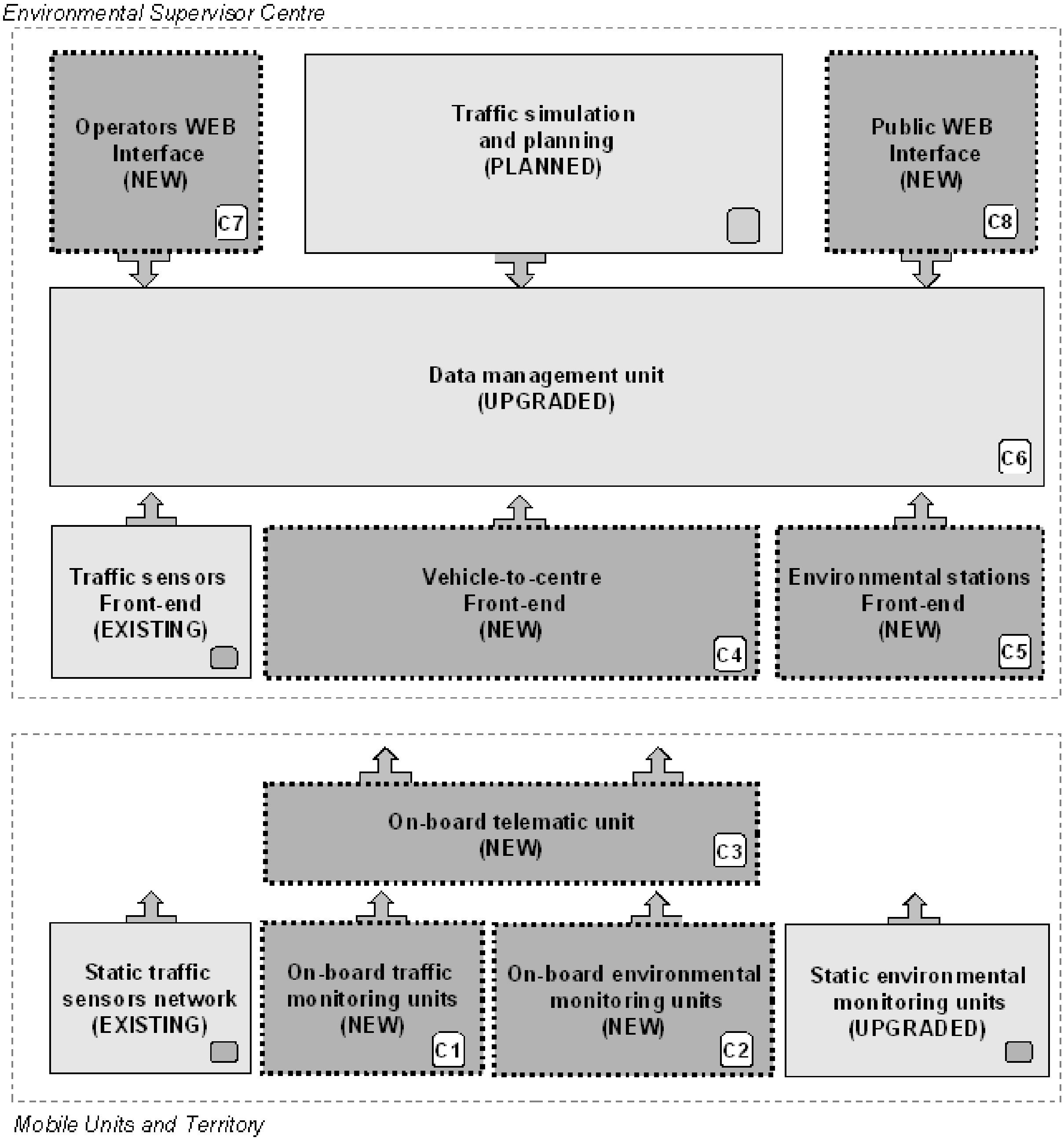


Figure 1: INTEGREEN system architecture [1].

The Action is structured in two different tasks, each of them covering a specific domain of the system architecture.

In Task 2.1, the components that are part of the new Environmental Supervisor Centre (i.e. (i) the data gathering module; (ii) the vehicle-to-centre front-end; (iii) the environmental stations front-end; and (iv) the operators and public web interfaces) are analyzed and evaluated in terms of the technical and functional requirements. This task is responsible as well of the analysis of the traffic and air pollution baseline data, which is needed in order to calculate the environmental impact of the project. This study is based on (i) the available data provided by the traffic and environmental stations within the city, (ii) previous local reports and studies providing a detailed and accurate picture about the environmental situation in the urban area of Bolzano, and (iii) specific measurement campaigns carried out with the aim of collecting quantitative data capable of providing specific details about the environmental impact of urban traffic.

Task 2.2 is in charge on the other side to define the requirements of the mobile system for INTEGREEN, which is an automotive electronic platform that allows vehicles to have traffic and environmental detection capabilities, as well as communication functionalities, in particular with the vehicle-to-centre front-end at the Environmental Supervisor Centre. The functional analysis of the mobile systems is covered by deliverable D.2.2.1 [2].

The deliverables of Action n.2 are the ground layer for the following activities of the project, since most of the decisions regarding the planning, the implementation, the testing and the validation of the INTEGREEN system will be made on the basis of the functional indications defined at this level, and following the typical V-model approach [3] (Figure 2).

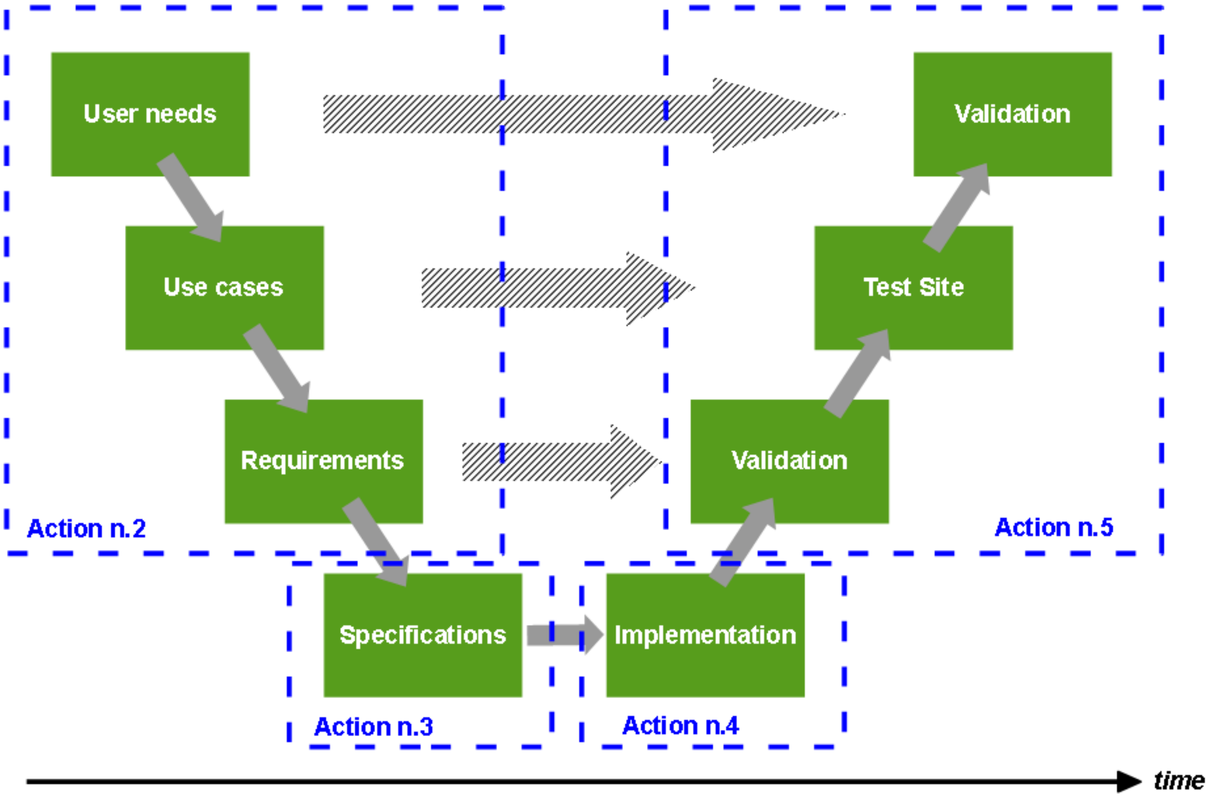


Figure 2: The V-model approach applied in the INTEGREEN project.

1.2 Requirement definition methodology

The methodology which is applied in this activity of requirements analysis is illustrated in Figure 3. It is composed by six sequential activities which aim (i) to assess and evaluate the starting baseline data and (ii) to identify the system requirements which can match the local needs and inefficiencies.

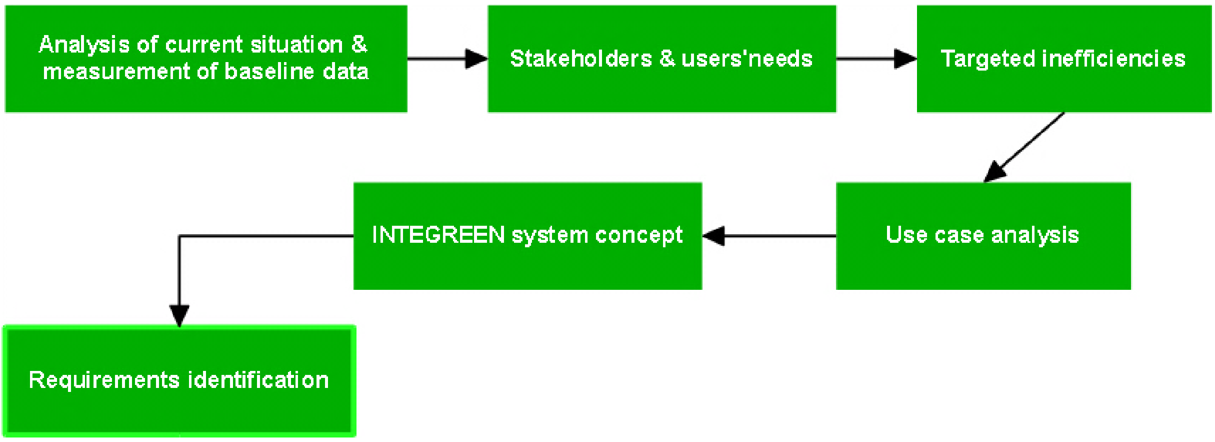


Figure 3: Adopted methodology for the analysis of the INTEGREEN requirements.

1.2.1 Analysis of current situation and measurement of baseline data

The results of the first activity are presented in Chapter 2, where a general description of the reference starting situation is provided. This task covers the following three main aspects:

- **an assessment of the natural constraints of the alpine urban context of Bolzano**, which have a significant impact in terms of local transport infrastructure availability. An initial evaluation of the current traffic and air pollution conditions as well of the local modal split is carried out, in order to highlight the main challenges that the project can efficiently contribute to address;

- **a technical evaluation of the today's monitoring traffic and air pollution systems**. This basic information is of utmost importance in order to understand at a future stage of the project (Action n.3) how to best extend or integrate the actual system functionalities in INTEGREEN;

- **a collection of reference baseline data**. This data represents the starting layer on the base of which all quantitative comparisons after the introduction of the INTEGREEN system are carried out.

1.2.2 Stakeholders and users' needs

This activity, presented in Chapter 3, focuses on the identification and evaluation of the needs of the INTEGREEN users and stakeholders. The output is a collection of high-level and unstructured needs, which present the different and sometimes conflicting perspectives of all involved actors. The needs are collected, where possible, through a direct relationships with the different users and stakeholders, and finally consolidated during the first INTEGREEN workshop. Where applicable, studies and reports available in the literature are considered in order to maximize the consistency of this analysis.

1.2.3 Targeted inefficiencies

Once the needs are identified, it is possible to distinguish a set of inefficiencies in terms of environmental impact of traffic within the urban area of Bolzano. The inefficiencies, presented in Chapter 4, are categorized in terms of pre-trip inefficiencies, i.e. the suboptimal aspects during a urban trip planning, and the en-route inefficiencies, i.e. the inefficiencies which take place when a traveler or driver is already on the road. This analysis is concluded through a collection of critical aspects in terms of traffic and mobility management, in order to balance the end-user perspective with the one of the public administration, which is intended to satisfy the conflicting requests of the whole local community.

1.2.4 Use case analysis

The list of reference targeted inefficiencies is the input for the definition of a set of reference use cases for INTEGREEN, which are illustrated in Chapter 5. A use case can be defined as a "*series of related interactions between a user (or more generally, an "actor") and a system that enables the user to achieve a goal*" [4].

In INTEGREEN, the objective of this analysis is to identify and describe specific reference situations that can be addressed within the project, and to start to specify the basic interactions between INTEGREEN users and system components that are needed in order to achieve them. This analysis is performed in such a way that it will be possible at the project end to define future cooperative use cases that are suggested by the international research literature and that will be implementable in Bolzano in the medium and long period on top of the INTEGREEN system.

1.2.5 INTEGREEN system concept

Based on the list of reference use cases, a detailed evaluation of the functionalities the INTEGREEN system and its components is performed. The overall system concept, presented in Chapter 6, is identified by carefully taking in consideration, among others, the reference architectures of international state-of-art research projects and demonstrative initiatives. The main output of this task is the definition of a set of reference *applications*, which clearly put in evidence how the different use cases can be implemented on top of the INTEGREEN system.

1.2.6 Requirements identification

The final step of this analysis is the definition of a set of a list of requirements, finally presented in Chapter 7, which intends to offer a complete description of the behavior of each of the components of the INTEGREEN system. The requirements, which are categorized as a function of their nature (i.e. functional, non-functional, interface and performance), are going to cover in part the overall system, and in part are going to be specific for each system component.

2 Analysis of current situation and measurement of baseline data

This chapter illustrates the current situation in the city of Bolzano and provides a set of baseline data which is going to be used as a reference indicator in order to measure the impact of the project on the local environment.

The chapter is organized as follows. The first paragraph describes the current situation in the city of Bolzano in terms of mobility, traffic and air pollution. The second and third paragraph describe the today's monitoring system of urban traffic and air pollution levels, respectively, where the first one is directly controlled by the Municipality of Bolzano while the second falls under the responsibility of the Local Agency for the Environment of the Province of Bolzano. The fourth and final paragraph concentrates on the baseline data assessment.

2.1 Mobility, traffic and air pollution situation in the city of Bolzano

2.1.1 Geographical scenario and road infrastructure

South Tyrol is an Italian bordering region in the north of Italy fully collocated in the alpine chain. The main centre of the region is Bolzano, a medium city of about 100.000 inhabitants, which hosts about one fifth of the entire South Tyrolean population[3]. Bolzano is located in a bowl at the confluence of three natural valleys (Adige valley, Isarco valley and Sarentino valley) and represents the main connection point of the local roads (Figure 4).

Figure 4: The city of Bolzano [Souce:tripadvisor.de].

[3] Based on the provisional data collected during the national population census in 2011 [20], there are 505.067 inhabitants in South Tyrol, and 102.869 of these (20,37%) live in the urban area of Bolzano.

Mobility in the area of Bolzano is burdened by several complementary aspects:

- being the main centre of the Province, where most of the central Public Administration services, private companies, schools (including the university) are located, Bolzano is the daily destination for a large amount of commuters coming from the remote towns of the regions;

- Bolzano is a node connecting the Province to the Corridor 1 (Berlin-Palermo motorway line), and therefore acts as a transit point for the high flows of people and goods which every day travel along the Brenner Corridor through the A22 highway;

- Bolzano is a well-known Point-of-Interest for mass tourism, due to surrounding natural landscapes (e.g. Dolomites), skiing facilities, summer resorts as well as local events such as the Christmas market; because of this, seasonal traffic peaks of relevant intensity periodically appear, in particular in correspondence to particular conditions (which include severe meteorological phenomena).

The geographical constraints significantly limit the enhancement of road infrastructure, in particular for transit traffic purposes. The main access roads to the city are today the following[4]:

- SS38 "MEBO" (Merano-Bolzano), which is a two-lanes freeway connecting Bolzano to Merano, the second main town of the Province, located in the Adige Valley;

- SS38, the old road connection Merano-Bolzano;

- SS12, the north-south road connection;

- SS42, which connects Bolzano to the Oltradige Valley.

Secondary roads connect Bolzano with other minor valleys as well:

- SS508, which connects Bolzano to the Sarentino Valley;

- SS241, which connects Bolzano to the Ega Valley;

- SP99, which connects Bolzano to San Genesio village;

- SP73, which connects Bolzano to the Renon plateau.

A primary role is also played by the A22 highway "Brennero-Modena", which connects Austria with the north of Italy. In the area of Bolzano, two toll gates are available:

- the toll gate "Bolzano South", with entrance in the industrial zone of the city;

- the toll gate "Bolzano North", with entrance in the north gate of the city through SS12.

[4] Please consider the following legend: SS = State Highway (*Strada Statale*), SP = Country Road (*Strada Provinciale*).

A comprehensive map of the main road infrastructure in the urban area of Bolzano is presented in Figure 5.

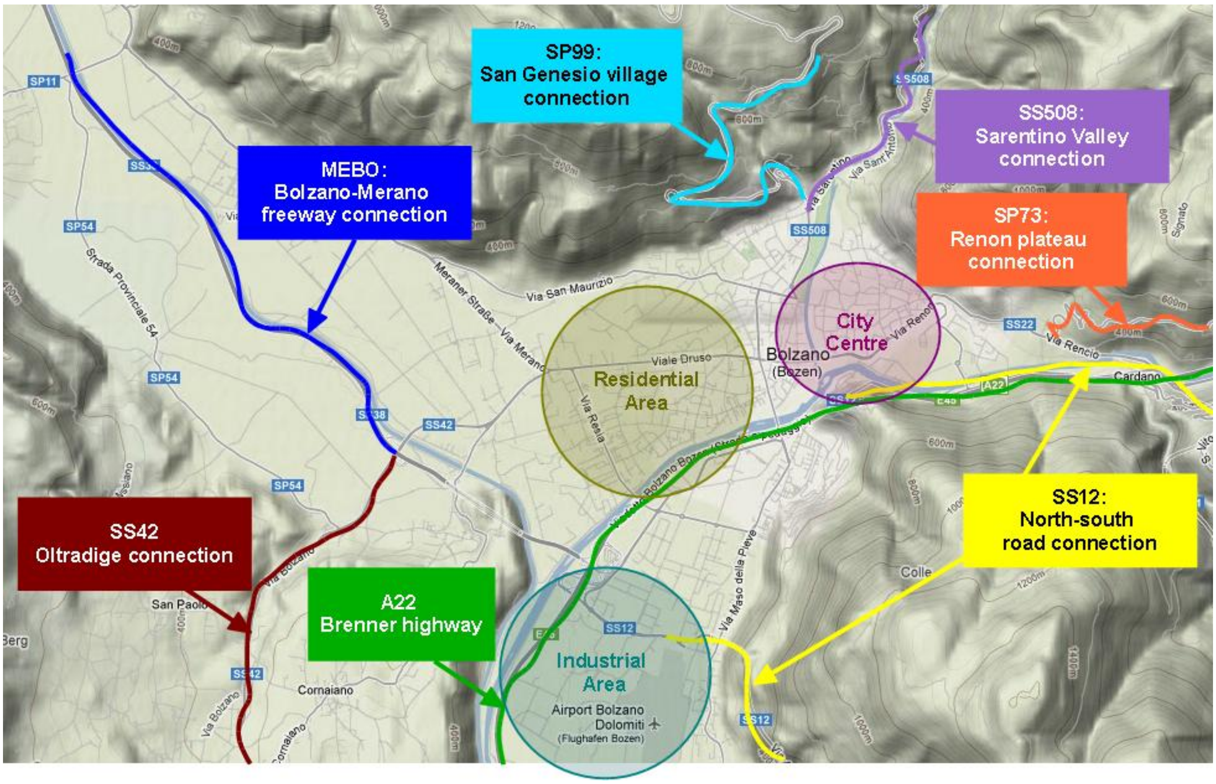


Figure 5: Road infrastructure overview in the urban area of Bolzano.

2.1.2 Traffic levels and modal split

Several studies performed in the past years under the coordination of the Mobility Office of the Municipality of Bolzano allow today to have an accurate and reliable picture of the traffic levels characterizing the city as well as of the mobility behavior of its inhabitants. The results of these studies have been the basis for the definition of the Urban Mobility Plan 2020 of the Municipality of Bolzano, defined at the end of 2009 [5]. The evaluation of traffic levels was mainly assessed by combining traffic data continuously collected through fixed measurement stations owned by the Municipality of Bolzano and the Province of Bolzano within the urban area and at the gates of entrance of the city, respectively. Mobility behavior information, on the contrary, was determined through specific surveys and origin/destination (O/D) analysis. The traffic and mobility data modeling was finalized with the aid of a traffic simulation tool, which has offered the local traffic managers the ability to evaluate the potential impact of long-term strategies.

Figure 6 presents the daily entering / leaving traffic flows in the city through the road connections with the surrounding valleys. It has been estimated that on average about 150.000 vehicles circulate every day in the city, and about 21.000 of these (14%) are heavy vehicles. A significant percentage of these flows (about 90.000 vehicles) has only a transit purpose, i.e. just enter and leave the urban area. Traffic levels can occasionally increase up to 30%, in correspondence to expected / unexpected events (e.g. main city events like

Christmas market, rainy days during the summer season).

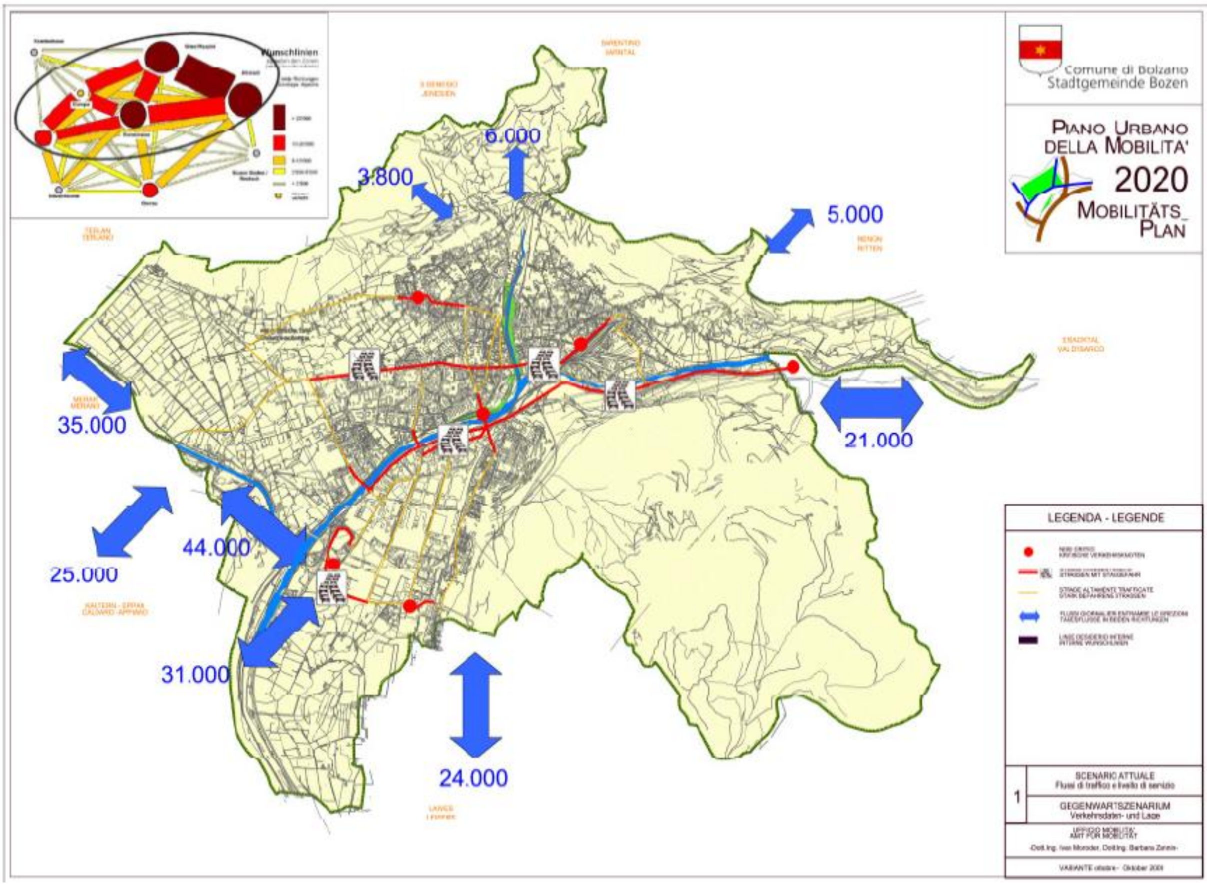


Figure 6: Traffic flows in the access nodes of the city of Bolzano [5].

Mobility habits of the inhabitants of Bolzano are presented in Table 1. Compared to most of the urban areas in Europe, the today's situation is particularly positive, since only the 33,9% (27,2% car, 6,7% motorcycle) chooses a motorized vehicle to move within the city.

Travel choice	%
Pedestrians	29,5%
Bicycle	29,0%
Public transportation (bus / train)	7,6%
Motorcycle	6,7%
Car	27,2%
Number of daily travels for inhabitant	3,5%

Table 1: Modal split in the city of Bolzano in 2009 [5].

The significant percentage of bicycle use (29%) is a direct consequence of the significant and networked bicycle road infrastructure which has been continuously extended in the past years. The bicycle road network only in part follows parallel the vehicular one; dedicated roads for bicycles and pedestrians only are available as well, in particular along the riversides of the rivers Isarco and Talvera which cross internally the city. Figure 7 presents the map of the present (in blue color) and future (in red color) bicycle road infrastructure, as well as the limited traffic zone (LTZ), colored in green. It is worth noting that the bicycle road network is not limited to the urban area, but also extends to the neighboring municipalities.

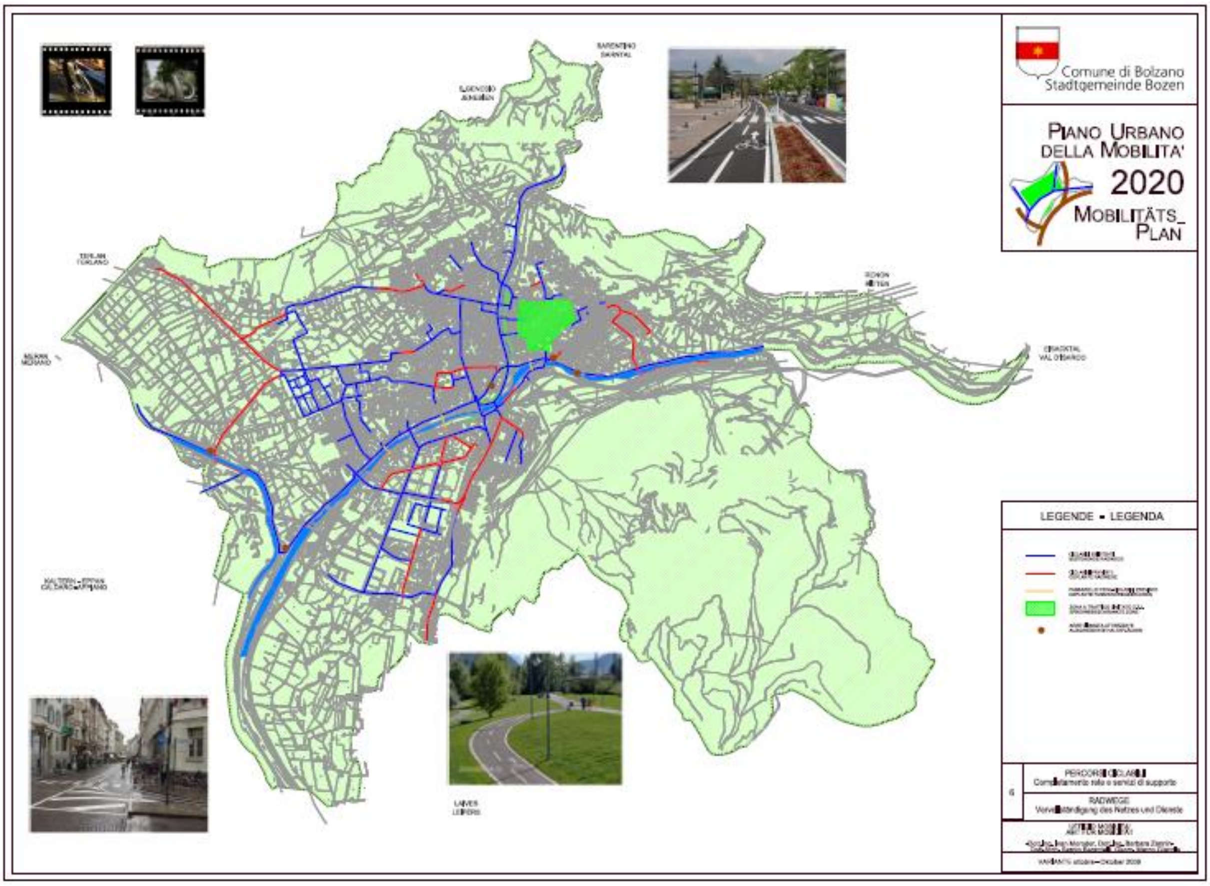


Figure 7: Bicycle road network in the city of Bolzano [5].

In order to further strengthen sustainable mobility within the city, it is of particular importance to efficiently address the two main challenges highlighted in the Urban Mobility Plan 2020, which are:

(i) **to reduce the vehicular transits in the residential districts**, i.e. the flows of vehicles which are just crossing the city, and do not have it as their final destination;

(ii) **to efficiently manage the flows of heavy traffic in the city**, in order to minimize its impact on the local welfare of citizens.

The long-term solution for these challenges is the creation of new road infrastructure for transit traffic, which will allow, among others, to more efficiently regulate the modalities of access of heavy vehicles in the urban area. The simulation of this future scenario, which takes into account the long-term measures identified in the plan as well as the increase trends of mobility demand, show the potential effectiveness of this intervention plan (Figure 8 and Figure 9).

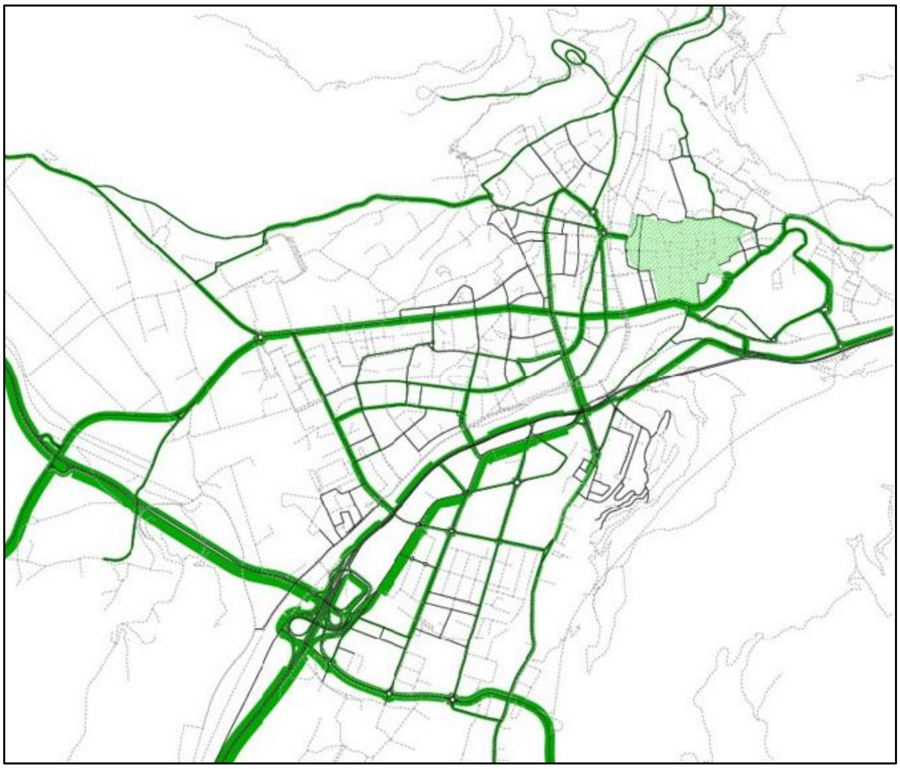


Figure 8: Traffic flows simulation in the city of Bolzano – baseline situation [5].

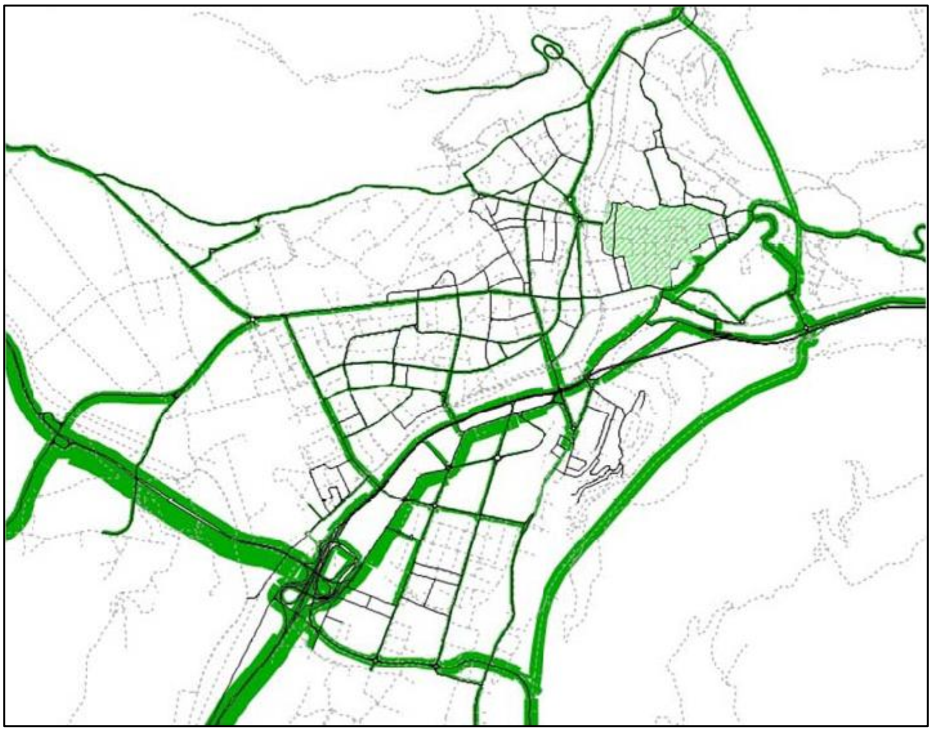


Figure 9: Traffic flows simulation in the city of Bolzano – future perspective [5].

In Figure 10 it is possible to appreciate an example of future policies that could be applied for the management of heavy traffic flows. The red roads are the paths that can be followed by heavy vehicles, and the green area is the zone which will be relieved by transit traffic.

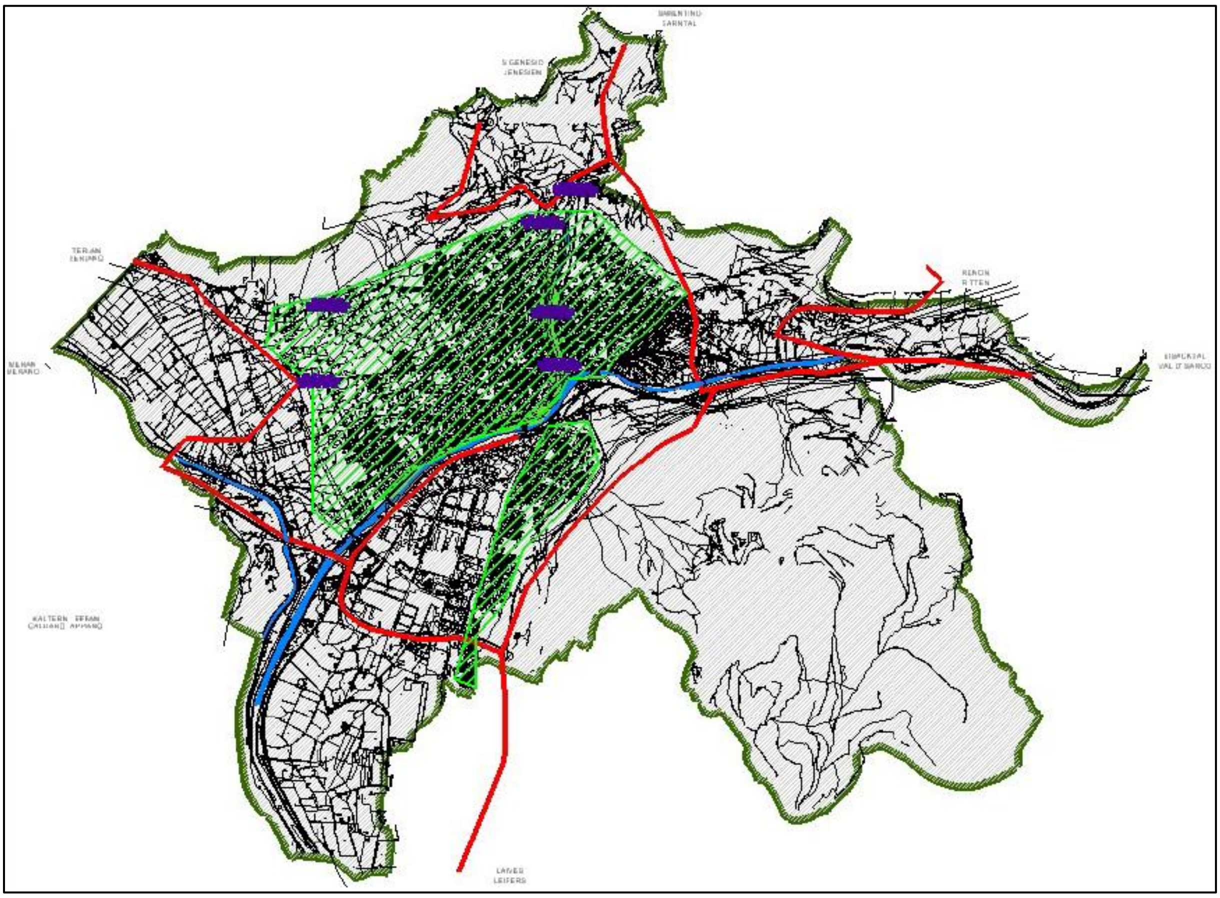


Figure 10: Heavy traffic management – future perspective [5].

2.1.3 Air pollution levels

The Province of Bolzano is an alpine region characterized by intense seasonal profiles. The highest levels of air pollution are typically identified during the winter season, when frequent phenomena of thermal inversion cause the stagnation of air masses. The complex orography and the katabatic winds create particular micro-climates, causing the formation of high pollutant concentrations in the valley bottoms.

Air pollution levels monitoring is performed by the Autonomous Province of Bolzano, in particular by the Local Agency for Environment. In line with the European Directive 2008/50/EC and the National Legislative Decree 155/2010, which is the Italian adoption of the aforementioned directive, the Province of Bolzano follows a Regional Plan for the Air Quality, originally approved in 2005, and which has been recently updated in November 2010. The plan represents a common reference for local stakeholders (in particular, the municipalities) in terms of:

1. air quality evaluation and measurement network organization;

2. programs for the reduction of air pollution in the areas where specific thresholds have been exceeded, which contain mandatory countermeasures to be applied in order to facilitate the re-entry to values accepted by law;

3. programs for the prevention of air pollution in the areas where air pollutant levels are within the accepted intervals, which contain mandatory measures to be applied in order to further increase air quality in a compatible way with sustainable development.

The plan is based on a detailed evaluation of the air pollution levels which have been determined through a static monitoring system composed by a network of environmental stations positioned at strategic sites in the region[5]. The measurements have allowed to determine the following statements:

- the levels of the classic air pollutants (**sulphur dioxide (SO_2)**, **carbon monoxide (CO)** and **benzene (C_6H_6)**) present since years a clear decreasing trend, allowing for an easy observance of the upper bound values defined by law (Figure 11, Figure 12 and Figure 13, where the orange chart is the one referred to the situation in Bolzano);

- the levels of **heavy metals** (lead, arsenic, cadmium and nickel), which are monitored since 2006 only in one environmental station in Bolzano at high exposure of traffic, are widely below the upper bounds level defined by law. In particular, the introduction of no-lead fuels have contributed to bring the levels of lead down to the instrumental detectability levels. In the past, benzene levels increased as a consequence of its use in fuel as a replacement for lead; this pattern however shifted to a decreasing trend thanks to the restrictive limitations that were introduced for the production of fuel;

- the levels of **benzo(a)pyrene (BaP)**, a polycyclic aromatic hydrocarbon (PAH) which is typically formed by incomplete combustion of carbon-containing fuels, is of main concern only in areas where the domestic wood combustion is still very high, in particular in the mountain areas;

- the levels of **particulate matters** (PM_{10} and $PM_{2.5}$), despite a remarkable decreasing trend in the last decade, and particularly from 2006, is still today an aspect of main concern in the region (Figure 14 and Figure 15). The reference laws impose not only that the annual average levels for PM_{10} is beyond a specific threshold (40 [$\mu g/m^3$]), but also states that the daily average levels cannot exceed the threshold of 50 [$\mu g/m^3$] for more than 35 times during a year. The decreasing trend is related to:

    (i) favorable meteorological conditions during the last winter seasons. Less harsh conditions and more frequent and stronger winds allowed to better dilute the air pollutants in the atmosphere. In 2010 colder temperatures during the winter season determined again an increase in the number of exceeding days;

[5] For more details concerning the environmental monitoring system in Bolzano, please refer to paragraph 2.3.

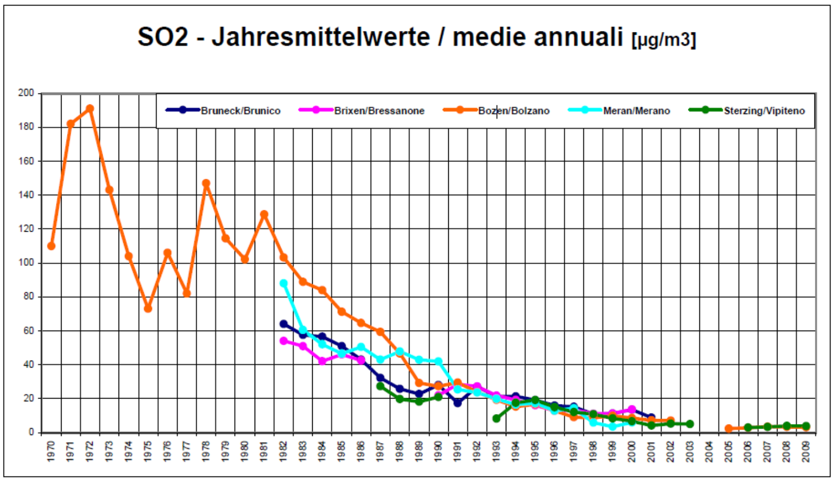


Figure 11: Sulphur dioxide concentrations in the Province of Bolzano [6].

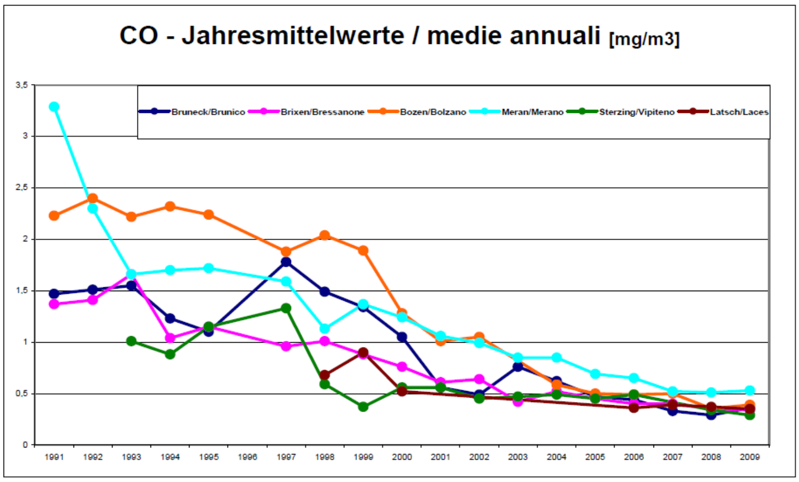


Figure 12: Carbon monoxide concentrations in the Province of Bolzano [6].

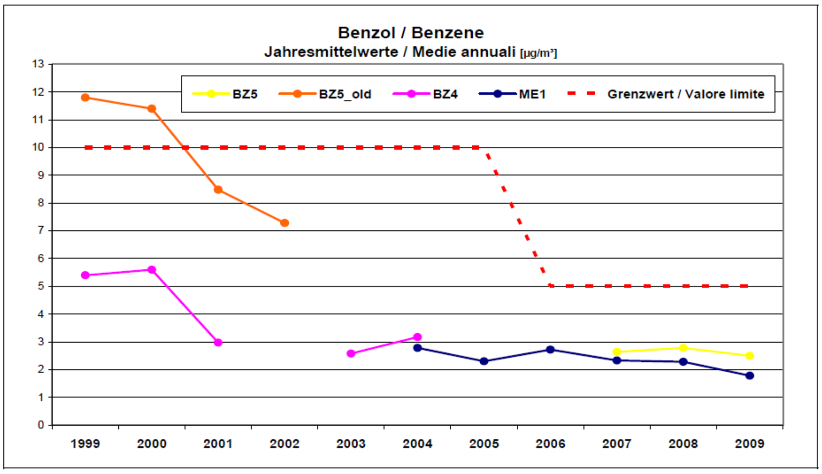


Figure 13: Benzene concentrations in the Province of Bolzano [6] [6]*.*

[6] The concentrations in Bolzano refer to stations BZ5 (Adriano Square) and BZ5_old, which is today dismissed.

(ii) specific measures adopted at a regional and municipal level, such as: the renewal of the circulating vehicles, the circulation limitations to the most pollutants vehicles, the fostering of public transport, and a city parking policy aiming at awarding the ecological vehicles.

Regarding the levels of PM2.5, similar considerations can be done, even if the decreasing trend is less accentuated (Figure 16). The annual average values are in the last years closed in the interval 15-18 [μg/m^3], which is remarkably lower than the upper bound value of 25 [μg/m^3].

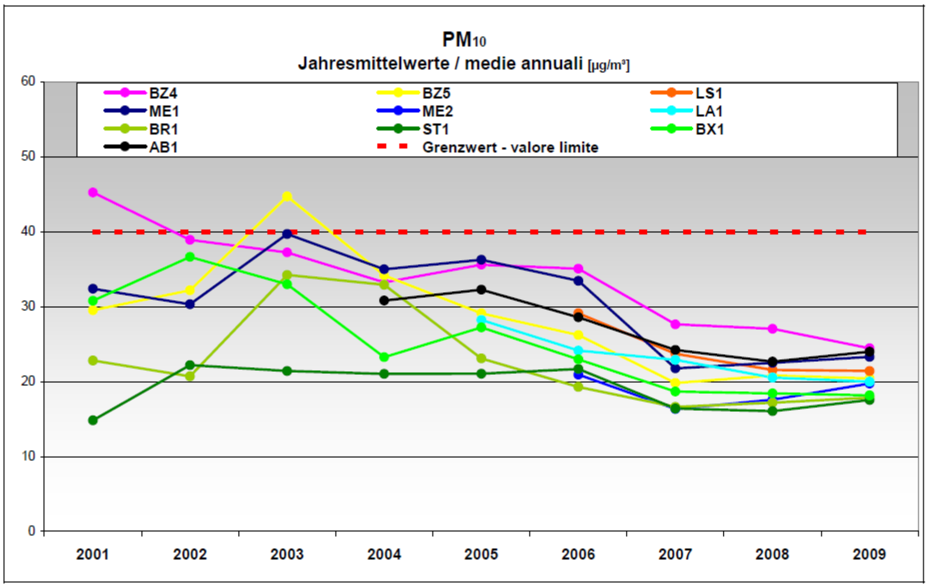


Figure 14: PM_{10} concentrations in the Province of Bolzano – annual average values [6].[7]

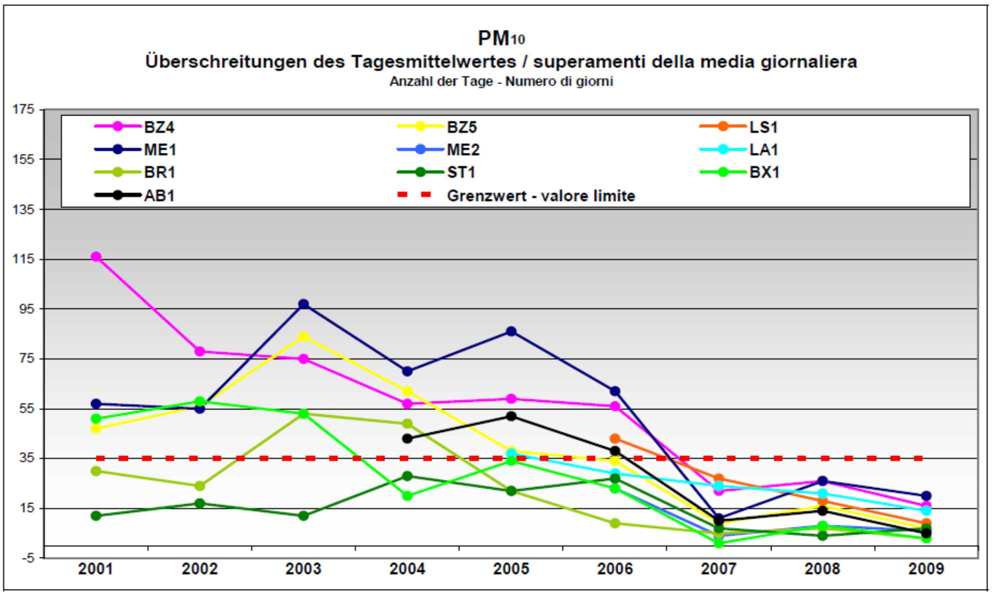


Figure 15: PM_{10} concentrations in the Province of Bolzano – number of exceeding days [6].

[7] Where not differently specified, the concentrations in Bolzano always refer to stations BZ5 (Adriano Square) and BZ4 (Claudia Augusta Street).

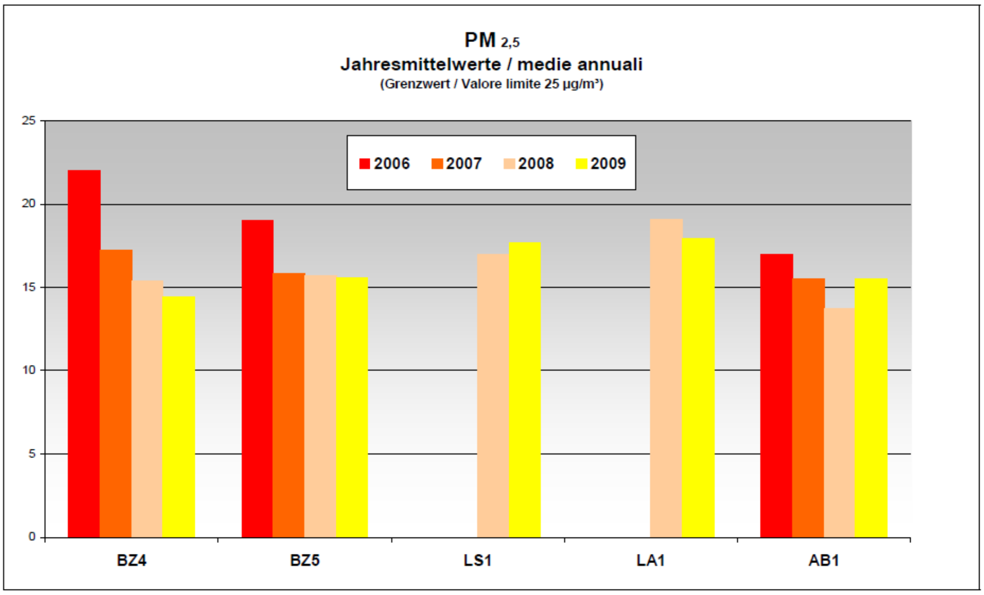


Figure 16: $PM_{2.5}$ concentrations in the Province of Bolzano – number of exceeding days [6].

- the levels of **nitrogen dioxide** (NO_2) <u>represent the main problem in terms of air quality in South Tyrol</u>, in particular in the main urban areas of the region. As it is possible to see in Figure 17, the annual averages of NO_2 emissions detected in Bolzano have been exceeding since years the upper boundary of 40 [$\mu g/m^3$]. The particular situation of the station AB1, which is located near the town of Bressanone at a distance of about 6 [m] of the A22 highway lanes, puts in evidence the strict relationship between traffic flows and NO_2 emissions. Moreover, the similar trend of the emissions detected in the station BZ4, not far from the A22 highway (Figure 30), puts in evidence that a prevalent NO_2 emission source in the city of Bolzano is not the urban traffic, but the highway traffic of the A22 corridor which crosses the city. Regarding the levels of nitrogen monoxide (NO), they have shown on the contrary a clear decreasing trend in the last years, which can be motivated thanks to the introduction of new euro classes in the field of vehicles homologation. These conflicting patterns can be justified in part because of their different production processes (emitted nitrogen oxides are primarily in NO form, while NO_2 is formed quickly but in a second step through chemical reactions in the atmosphere), in part because of the inefficiencies of specific euro vehicle classes (emission reduction has not been applied in a uniform way for both NO and NO_2, an inconvenient which should be overcome through Euro 6 diesel motors), and in part due to the concentrations of ozone[8].

- The levels of **ozone** (O_3) is also a topic of local concern. On one side, the average values are showing an increasing trend (Figure 19), while on the other side the maximum and peak values are significantly decreasing. In general, the maximum concentrations of ozone are detected in locations at high altitudes which are far from the nitrogen oxides sources (i.e, the road infrastructure).

[8] Several studies in the literature have demonstrated that a relevant reduction of NO_2 is possible if NO concentrations are equal or less than the concentrations of O_3.

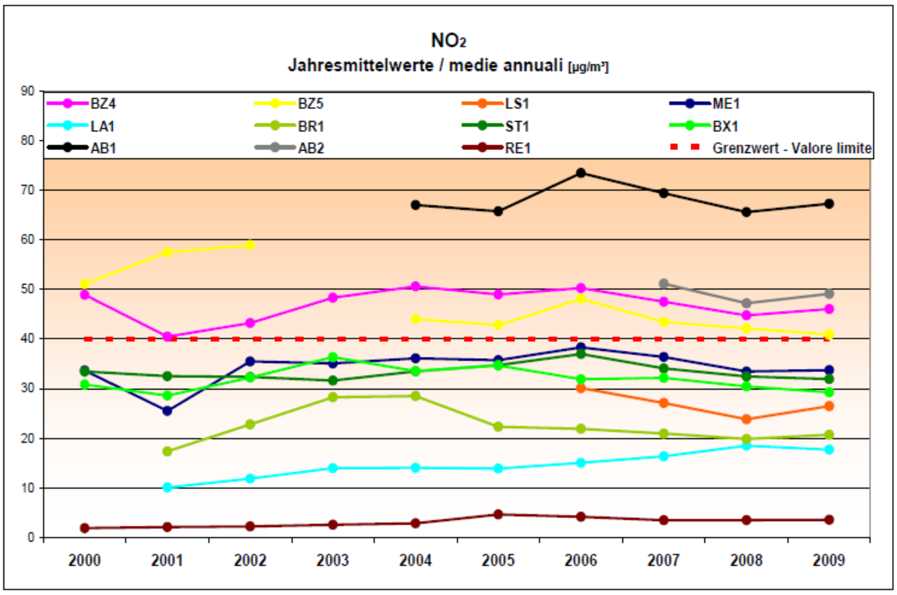


Figure 17: NO2 concentrations in the Province of Bolzano – annual average values [6].

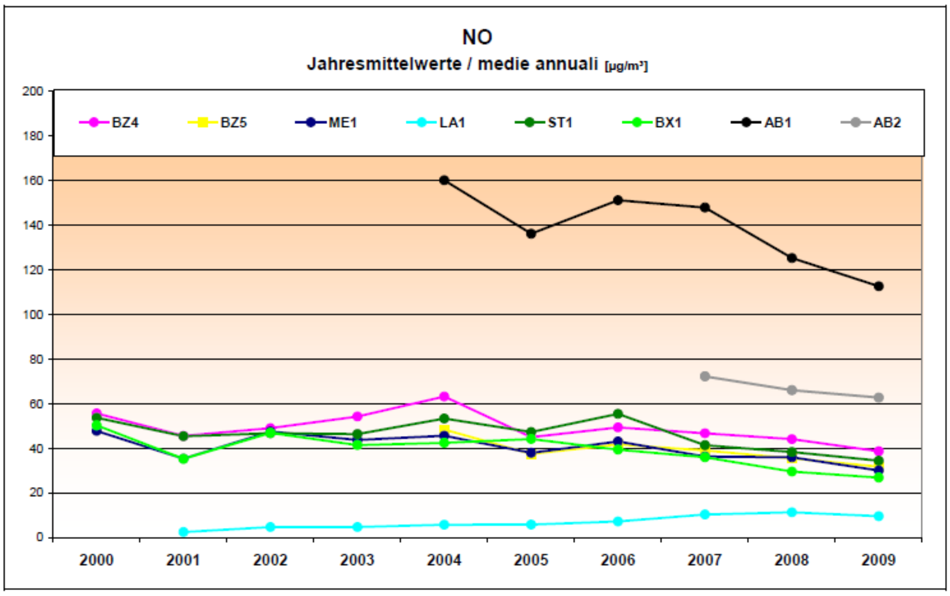


Figure 18: NO concentrations in the Province of Bolzano – annual average values [6].

As it possible to see in Figure 20, the reference value for the health protection, which is equal to 25 days/year in which the daily average value (calculated over a period of eight hours) is more than the reference threshold of 120 [µg/m^3], has been significantly exceeded in numerous locations at regional level, and even in Bolzano.

It is also worth noting that in several occasions, in particular during the summer season, during very hot days, characterized by high pressure, temperatures and sunstroke, the boundary "information" limit of 180 [µg/m^3], which is referred to averages calculated on an hourly basis, is often exceeded, with the necessity to properly inform the local population (Figure 21).

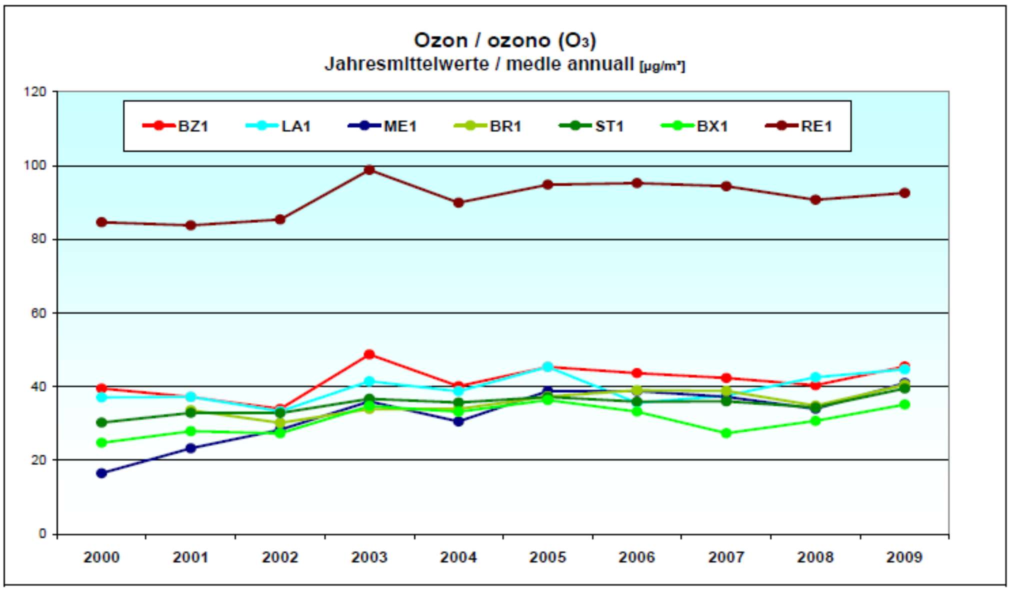


Figure 19: O3 concentrations in the Province of Bolzano – annual average values [6] [9].

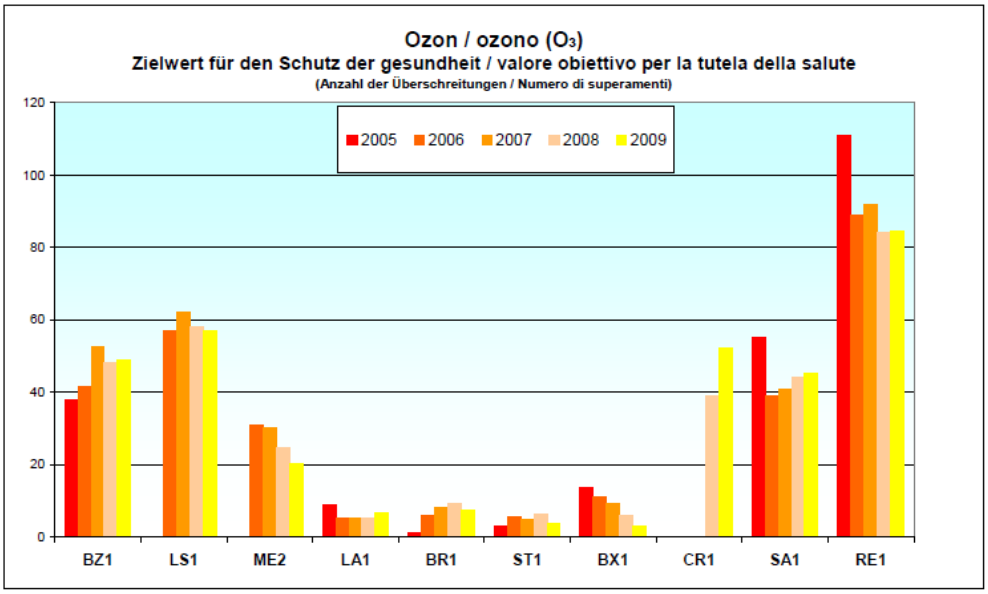


Figure 20: O_3 concentrations in the Province of Bolzano – number of exceeding days referring to human health protection objective value [6].

2.2 Traffic Management Centre of the city of Bolzano

Traffic monitoring and control in the city of Bolzano falls under the responsibility of the local traffic police, which perform this task in cooperation with the Mobility Office of the Municipality of Bolzano by means of a dedicated traffic management centre (TMC), located in a peripheral area of the city near the industrial zone (Figure 22). A complete overview of how traffic is managed within all the South Tyrolean region is available in [7]. The TMC as it looks like today was built in 2002, in strong cooperation with the local company Famas System.

[9] The concentrations of ozone in Bolzano are measured by station BZ1 (Amba Alagi street).

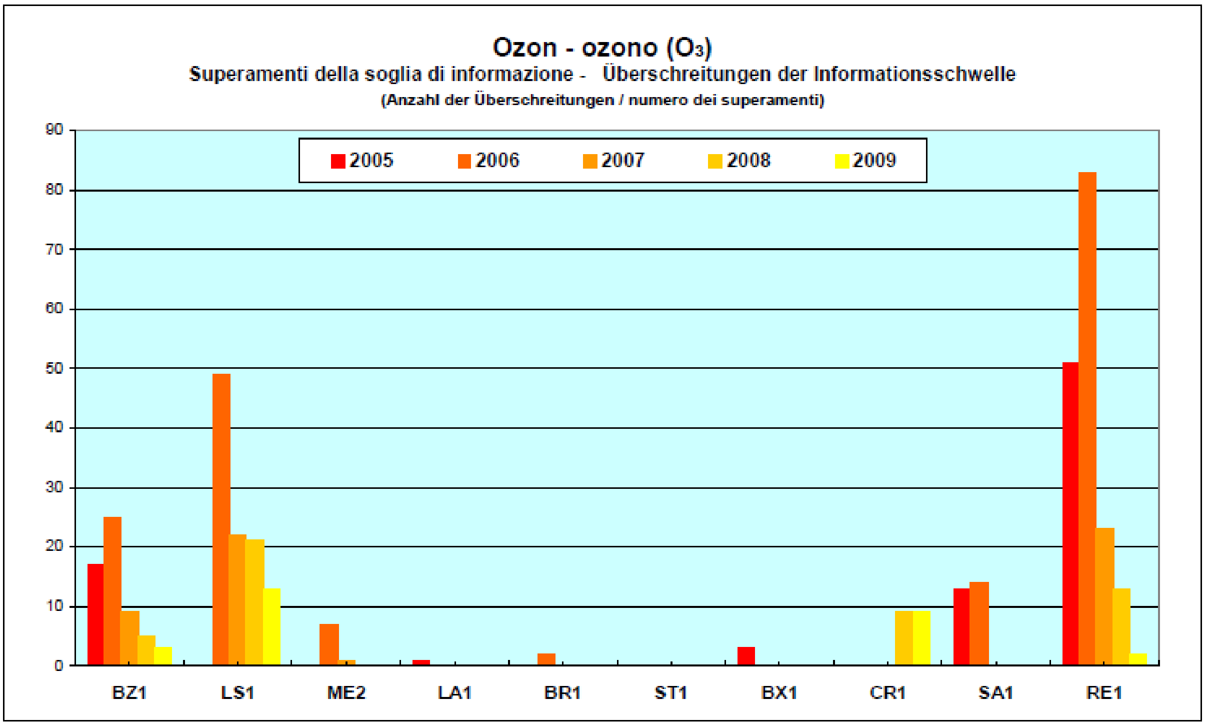


Figure 21: O_3 concentrations in the Province of Bolzano – number of exceeding days referring to information boundary levels [6].[10]

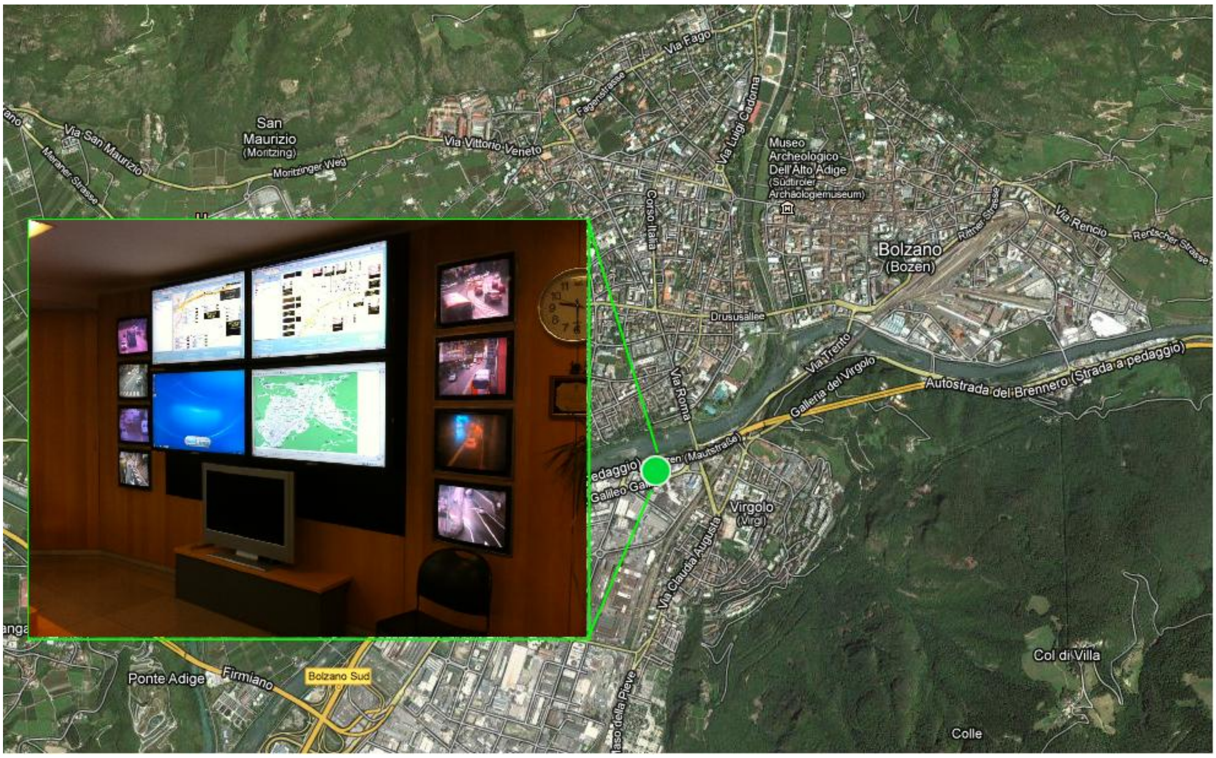


Figure 22: Traffic Management Centre of the city of Bolzano.

[10] The concentrations in Bolzano refer to stations BZ1 (Amba Alagi street).

The high-level architecture of the TMC is presented in Figure 23. Six main systems are directly managed by the TMC:

- a **traffic lights management system**, which is in charge of controlling the proper functioning of the network of traffic lights installed in the city;
- a **parking guide system**, which collects the real-time information about the free parking slots of the main parking areas of the city and publish it on dedicated Variable Message Signs (VMSs);
- a **traffic detection system**, which allows to collect traffic data at specific crucial points of the urban road network;
- a **network of VMS**, which provide the drivers with general information about the current traffic conditions in the city;
- a **video-surveillance system** which covers the main transit roads of the city;
- an **automatic accident and queues detection system** over the "Arginale" road[11],

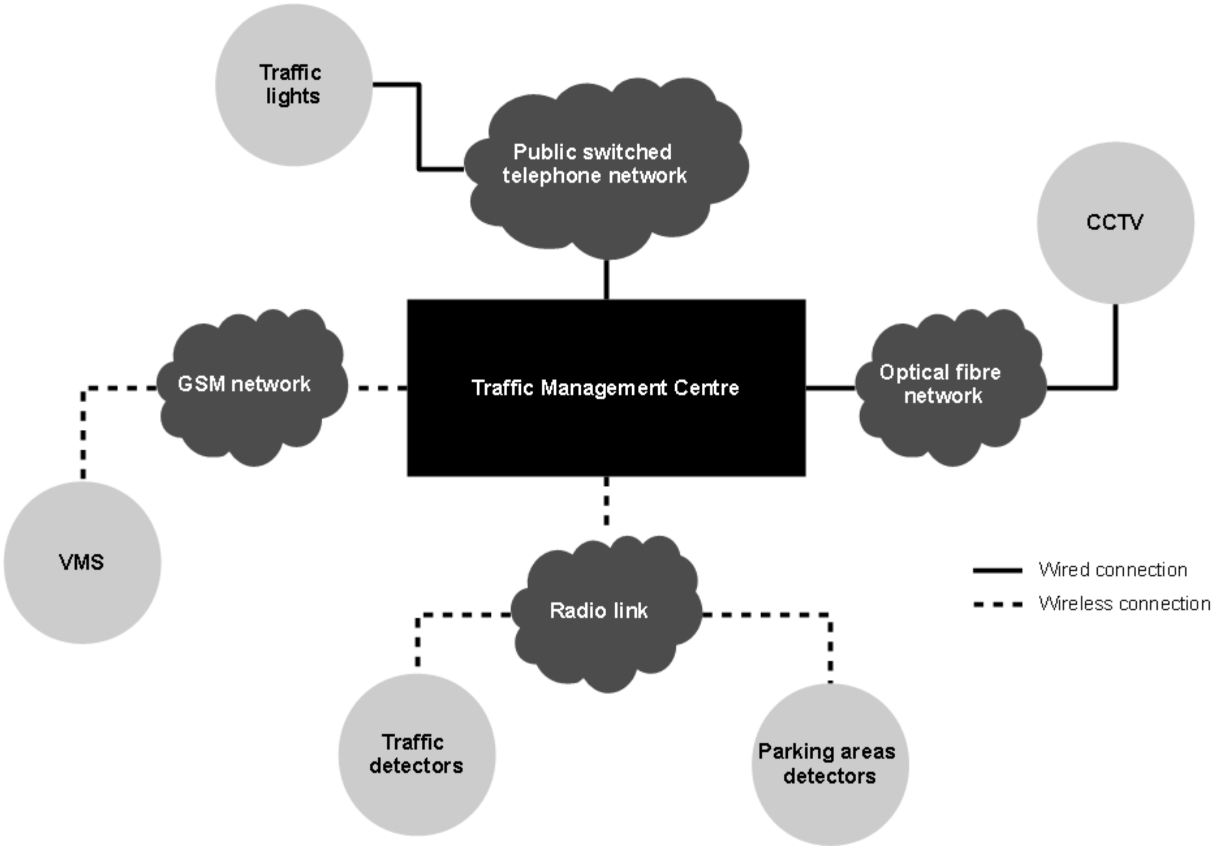


Figure 23: High-level architecture of the TMC of Bolzano.

[11] The road "Arginale" is one of the most important transit roads which crosses the city in direction north-south, parallel to the Isarco river and under the A22 highway. Drivers can take this road only in direction south, and is mainly destined to transit traffic.

The TMC can be characterized in three main different “layers”:

- a **data source layer**, which is composed by all devices, sensors and actuators installed on the road network and which allow to regulate and monitor the urban traffic flows, i.e.:
  - ✓ the traffic lights, including the detectors which are specifically used in order to recognize special vehicles (i.e. buses) and to give them priority at the traffic lights intersections;
  - ✓ the parking slots detectors of the main parking areas;
  - ✓ the traffic detectors;
  - ✓ the VMSs;
  - ✓ the video cameras;

  The geographical location of traffic lights (in red color), video cameras (in green color) and inductive loops (in pink color) that are today in function is illustrated in Figure 24.

- a **data communication layer**, which allows the field devices to be connected with the control centre. The connection is based on a variety of wireless and wired communication technologies, i.e.:
  - ✓ a dedicated analog data channel over the public switched telephone network, which is used for the connection of the traffic lights;
  - ✓ an optical fibre network, which is used for the connection of the video cameras;
  - ✓ a GSM network, which is used for the connection of the VMSs;
  - ✓ a proprietary radio link at the frequency of 440.7 [MHz] for the connection of the parking slots and traffic detectors.

- a **control centre layer**, which allow the traffic officers to get an immediate picture of the traffic conditions in the city through dedicated user interfaces and in particular by means of a videowall composed by eight monitors.

2.2.1 Traffic lights control

The traffic lights management system, which avails of Siemens technology, is in function since 2002 [8], and allows traffic officers to design the cycles of the traffic lights as well as to maintain all the traffic lights infrastructure. The traffic lights communicate with the traffic lights management system mainly on top of a dedicated analog data channel over the public switched telephone network, which is actually significantly limited in terms of bandwidth[12]. The continuous development of an own municipal optical fibre network, which extends today for about 10.000 meters of cables, is allowing today to gradually migrate from this old and

[12] The maximum theoretical bandwidth of a digital transmission over a public switched telephone network is equal to 43 [Kbit/s], which can be increased up to 55.6 [Kbit/s] by means of more efficient signal coding techniques.

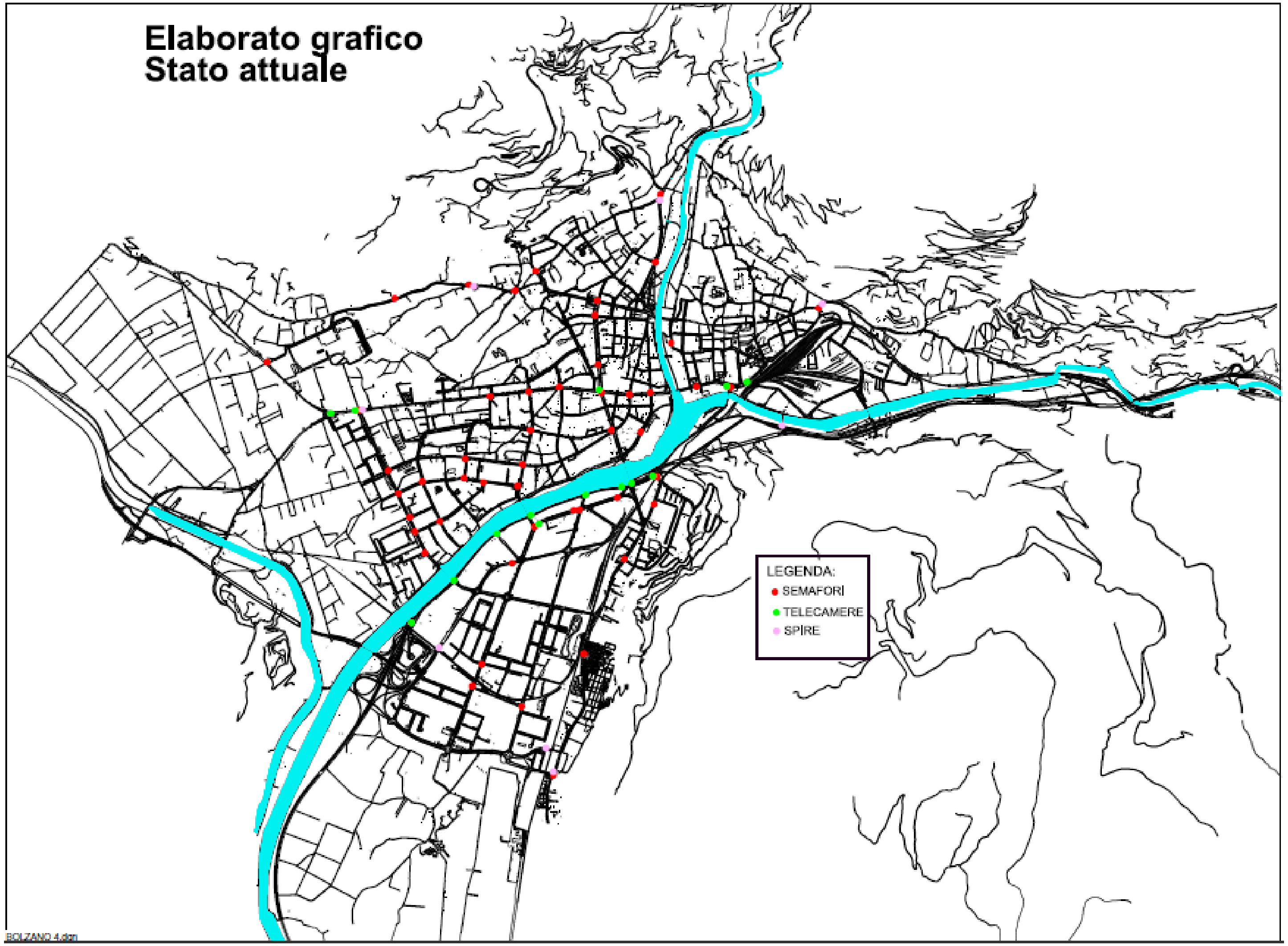


Figure 24: Map of different roadside equipments controlled by TMC.

restrictive data communication channel, a migration process which now complete at about 30%. The adopted optical fiber technology is the single mode one, i.e. which is capable to support only one transmission interval in the wavelength domain. A Wavelength Division Multiplexing (WDM) technique allows multiple signals to be transmitted together in both direction, i.e. in *full-duplex* mode, up to a data rate of 100 [Mbit/s].

At the control centre layer, it is possible to visualize the current status of the traffic lights. The operators in the control room can only switch off the traffic lights, and not to introduce a change in the traffic lights cycles. This task can only be performed by an authorized traffic operator by means of a specific computer program, which can be run from a local PC in the local traffic control centre network running a Microsoft Windows operating system. Thanks to a simple graphical user interface (Figure 25), it is quite simple for an operator to visualize and define the cycles of the traffic lights, to create green waves and to modify the regulations of the traffic lights detectors.

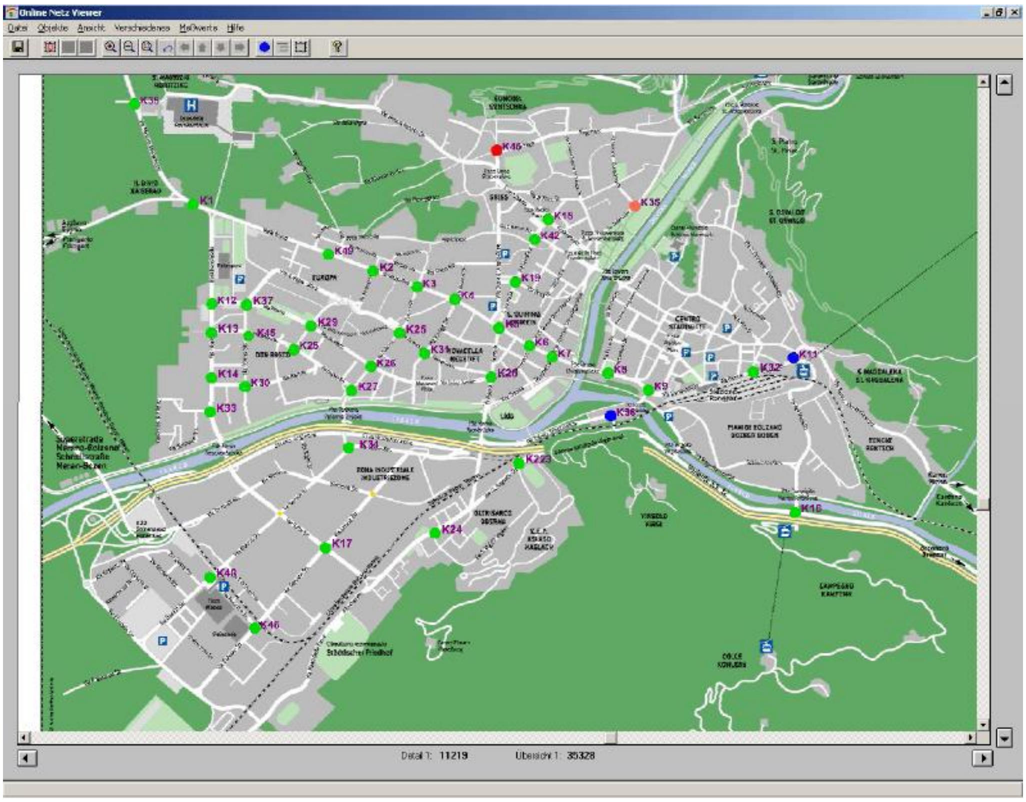


Figure 25: Graphical user interface of the traffic lights control program.

2.2.2 Parking Guide System

The parking guide system was first installed in 1998 as part of an autonomous system with the objective to efficiently navigate drivers towards the main parking area of the city by means of a network of VMSs. Each VMS does not only inform about the current availability of free parking slots in the parking areas, but also provide general traffic information in the city, in particular in case of particular traffic limitations in direction to the city centre. For example, during periods of traffic peaks caused by tourists flows, the access to the city can become very difficult, and a typical suggestion is to adopt a park&ride scheme, i.e. to park their car in one of the parking areas in the periphery and to reach the city through a public transport connection, as illustrated in the figure below.

At present, the parking guide system manages eleven parking areas: ten are with fee (seven are private and three are public) and one is free of charge.

The data about the level of occupancy of the different parking area is gathered at the control centre through a continuous polling to the ticketing systems and/or by counting entering and leaving vehicles by means of one or more inductive loops installed on the ramps.

The bi-directional connection is performed through a dedicated radio link at the own frequency of 440.7 [MHz], which guarantees a maximum data rate of 4.8 [Kbaud/s]. The base station antenna is installed on the roof of the TMC, and is implemented by means of two dipoles that guarantee a slight directionality in order to have a stronger transmission capability over the area where most of the parking areas are located. The remote stations antennas are on the contrary omni-directional.

A software client is at disposal of the traffic officers in order to let them easily manage and control the system, as well as to visualize and analyze the available data (Figure 26).

Figure 26: Graphical user interface of the parking guide management system.

In particular, the client offers the following main functionalities:

- **the setting of the messages to be displayed over the VMSs**, which are delivered through the GSM network. The messages can be configured manually but even automatically, on the base of custom criteria (e.g. at predefined schedules and/or in specific areas of the city, in correspondence of particular triggers, for example when the number of available parking slots is lower than a specific threshold, etc.);

- **the statistical elaboration of historical data** and the production of reports which are available both in graphical and textual form;

- **the maintenance of the system**. In particular, the operator can define a certain number of thresholds in correspondence of which the field devices are obliged to send to the central system a message of alarm.

A comprehensive map of the parking areas and VMSs managed by the system is available in Figure 27. The green points refer to complete VMSs (i.e. with indicators for the free parking slots), while the red ones indicate traditional VMS, very similar to the ones which are commonly used in the highways (as shown in the nearby figure).

2.2.3 Traffic detection

A network of static traffic monitoring stations which avail of **inductive loops technology** [9] has been installed in the past years with the primary intention to get quantitative data about traffic flows on the main road corridors of the city. The data are used only by the traffic officers as a support for real-time traffic control operations, but more frequently to perform posterior analysis, in particular during the local transportation planning activities, which are specifically carried out by means of an off-line traffic simulator, as already stated in paragraph 2.1.2. The traffic simulator in question is VISUM, produced by the company PTV [10], which allows to model a transport network and the local mobility demand on the base of multiple data sources (e.g. traffic data, public transportation data, etc.) and the potential impact that different long-term strategies (i.e. ITS-based strategies, for example road pricing, and infrastructure-based strategies, for example the creation of new roads) can have on it.

At present, eight traffic monitoring stations are installed over the urban road network, as already indicated in Figure 24. Each station is able to record the following parameters for each vehicular transit:

- timestamp;

- speed;

- direction;

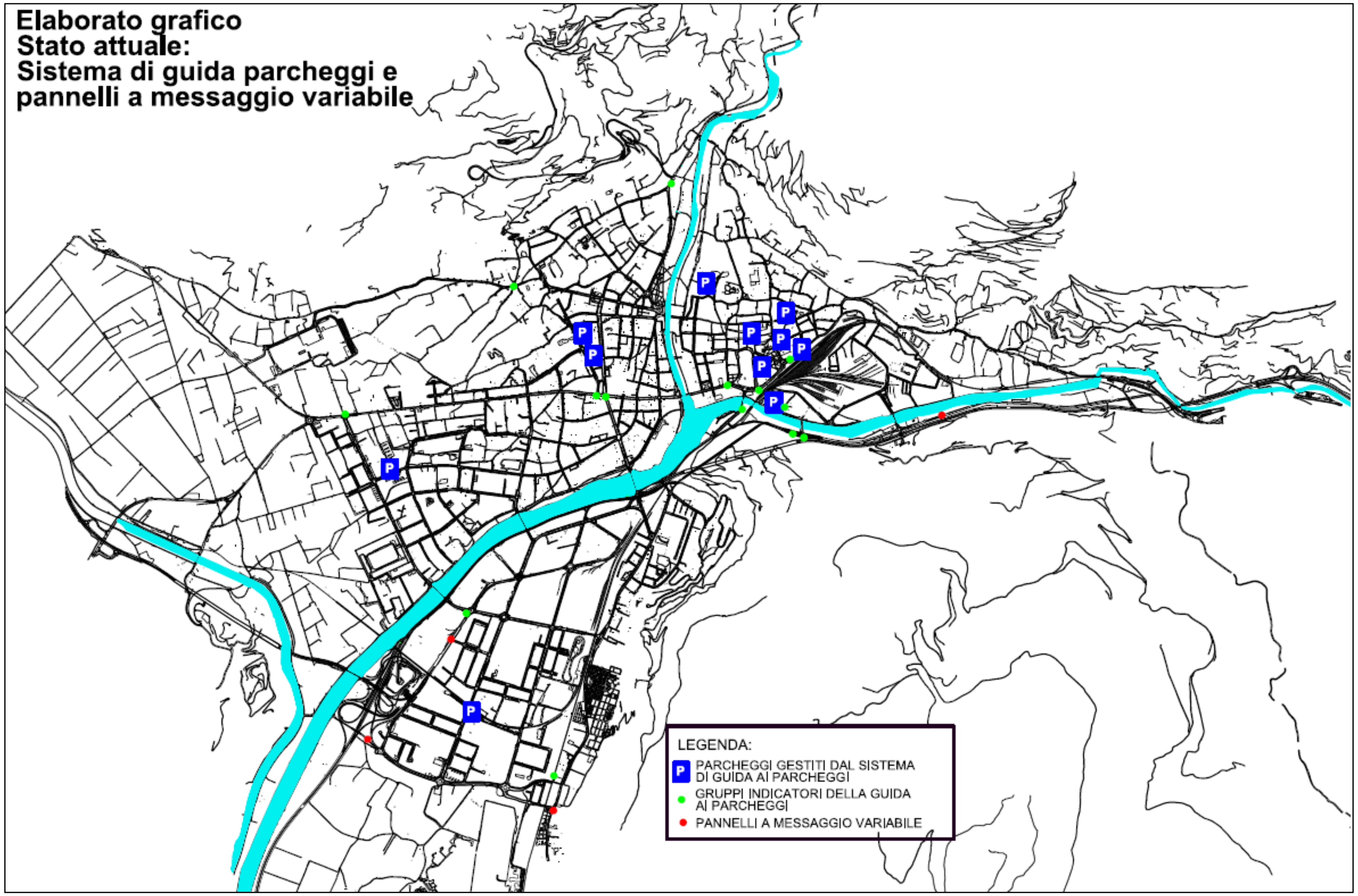


Figure 27: Parking areas and VMSs currently managed by the parking guide system.

- gap;
- headway;
- vehicle class, according to the Italian classification standard ITALY10 which associates each vehicle to one of ten categories, as illustrated in Table 2.

Class	Vehicle typology	Class	Vehicle typology
1	Motorcycles	**6**	Medium trucks
2	Cars	**7**	Trucks with trailers
3	Cars with trailer	**8**	18-wheelers
4	Vans	**9**	Buses
5	Small trucks	**10**	Others

Table 2: Italian vehicular classification standard.

All the collected data are periodically transmitted to the traffic management centre by means of the radio link which is shared with the parking areas detectors. At the control centre layer, the data are stored and at disposal for real-time and off-line analysis. For this task, the traffic officers avail of a visualization client, which is fully integrated with the software interface for the parking guide system (Figure 27). The following main functionalities are implemented:

- **the real-time traffic control over the monitored areas**. The stored traffic data are presented to the traffic officer in an aggregated form in such a way that is quite immediate for him/her to understand if it necessary to activate a possible intervention procedure. The elaborated data can be presented both numerically and graphically;
- **the off-line traffic data analysis**. The traffic officer can ask the system to produce reports which provides a detailed historical picture of the traffic conditions, both in the short and long-term by simply identifying the time interval of interest. This data are then typically used in the transportation planning activities;
- **the maintenance of the system**, in a very similar way as for the parking areas detectors.

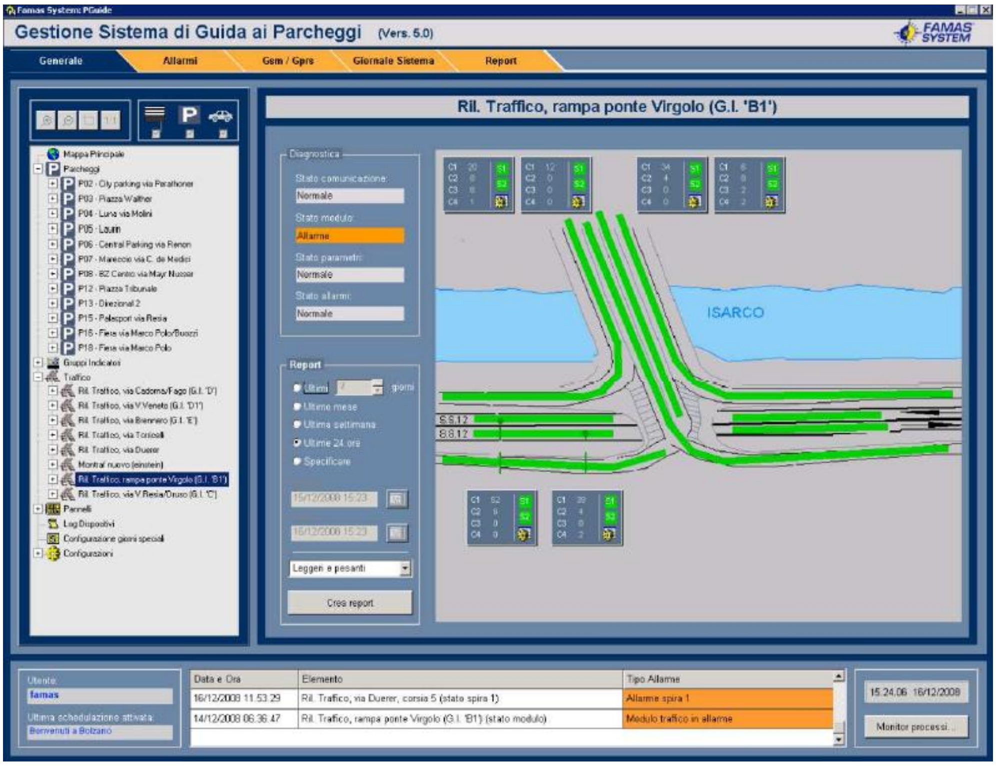


Figure 28: Graphical user interface of the traffic detection system.

2.2.4 Video surveillance

The real-time traffic control operations performed by the local traffic police are mainly carried out on top of a closed-circuit video-surveillance system composed by 29 cameras installed at the main road intersections of the city. Both analog (twenty cameras) and digital (nine cameras) technologies are in use. About one third of the cameras are installed in correspondence of the “Arginale” road. All the cameras are not pan-tilt, i.e. it is not possible to remotely rotate them in order to dynamically change the monitored area.

The video signals are transmitted to the traffic management centre only by means of the optical fibre network which is in part used even as communication backbone with the traffic lights, as already pointed out in paragraph 2.2.1. Thanks to the high available bandwidth, this communication channel can suit very well with the high transmission requirements of the video signals. The videos are directly visualized on the videowall of the control room, and not archived since no post-processing activity is actually foreseen. At present, the video signals are not further shared either with other local security forces or with other traffic management authorities in the region.

The videos acquired by the cameras installed on the “Arginale” road can be automatically elaborated in order to early detect the presence of some events that can reduce the road safety, in particular traffic jams and accidents. In the case an event is detected, an alarm can be fired and visualized on the videowall. However, this functionality is currently not operational.

2.2.5 Future expansion of monitoring capabilities

The traffic management centre of the city of Bolzano is involved in an on-going process of significant expansion of its monitoring capabilities, which will allow to reach the following targets:

- **traffic detection capabilities reinforcement**. More specifically, <u>five static traffic monitoring stations based on the inductive loop technology</u> will be installed in the urban road network in order to increase the amount of local traffic data sources and thus to improve the reliability of the traffic simulation outputs;

- **traffic control capabilities reinforcement**. More specifically, <u>eight digital video cameras</u> will be added to the closed-circuit video surveillance system. Three cameras will have the pan-tilt option. Thanks to this, traffic officers will have the possibility to check on a real-time basis the traffic conditions in areas of the road network which are at present not covered by the system;

- **installation of an origin/destination traffic flows detection system**. It is a system based on *Automatic Number Plate Recognition* (ANPR) technology, which allows to automatically recognize the number plate of each vehicle through an *optical character recognition* (OCR) process of the filmed plates. Fifteen ANPR cameras, which typically avail of an infra-red illuminator as well in order to properly work even at night, will be installed in correspondence to the main entry road gates of the city, with the purpose of analyzing more in deep in particular the transit traffic patterns. Data acquired by one source (origin) is combined with the data acquired by another source (destination), in order to identify possible matches and thus to determine the travel choices of each vehicle. On the base of this elaboration chain, it is possible for example to estimate:

  - ✓ <u>the total number of transit vehicles sharing the same origin/destination path</u>. This information is particularly important in transport planning activities, in order to have quantitative (and thus more reliable) values concerning local mobility demand;

  - ✓ <u>the average travel time on a certain origin/ destination path</u>. This information can be very precious for drivers, and be efficiently delivered through proper info-mobility channels.

It is worth noting that this kind of system can potentially put in discussion the privacy of drivers, since it is possible to track the travels of each vehicle and associate them to a specific person (i.e., the vehicle owner). This issue is typically managed in advance by immediately deleting the association between vehicle and its identity through the association of a unique random number to each number plate.

- **installation of a first set of static environmental stations**, aiming at the real-time measurement of the air pollutant concentrations at the roadside level, i.e. very near to the traffic emission source. This internal investment, which is complementary with the one foreseen in INTEGREEN, allows to early exploit the environmental monitoring capabilities that the traffic management centre is going to develop within the project. The four portable stations are based on electrochemical cells, which allow to acquire quicker but less precise data than the chemiluminescence technology which is typically adopted by the regional agencies for the environment for the air pollution measurements which are mandatory by law. The stations will be installed in points of the city that are not going to be directly monitored within INTEGREEN. The air pollutants that are going to be monitored, in line with the set of requirements that are defined in this deliverable, are:

    - ✓ **nitrogen oxides (NO_X) and dioxide (NO_2)**, in order to get measurements of both NO and NO_2;
    - ✓ **carbon monoxide (CO)**;
    - ✓ **particulate matters**, and more specifically **$PM_{2.5}$** (in order to anticipate the future requirements on this air pollutants class);
    - ✓ **volatile organic compounds (VOC)**;
    - ✓ **ozone (O_3)**.

  Meteorological variables such as **temperature, humidity, wind speed and direction, solar radiation** are monitored as well in order to efficiently calibrate the dispersion models of air pollutants.

  The environmental data are going to be periodically delivered to the traffic management centre by means of a wireless link, which can be the proprietary radio link, the cellular network or other suitable wireless communication technology.

- **installation of a meteorological station on top of the traffic management centre**, which offers the possibility to acquire precise and quantitative data about the current meteorological conditions within the city. The station is going to measure a full set of meteorological parameters, i.e. type and intensity of the precipitation, temperature and humidity, wind speed and direction. Thanks to this complementary data, it is possible to characterize traffic patterns as a function of the meteorological situation, and thus to create a deeper understanding of the local mobility demand shift which occurs in these specific conditions. This information can be very important in order to predict for example traffic jams induced by bad weather.

The expanded architecture of the Traffic Management Centre is shown in Figure 29. It is worth noting that the communication channel for the new systems can be different from the indicated one, and will be finally identified only during the design and implementation activities.

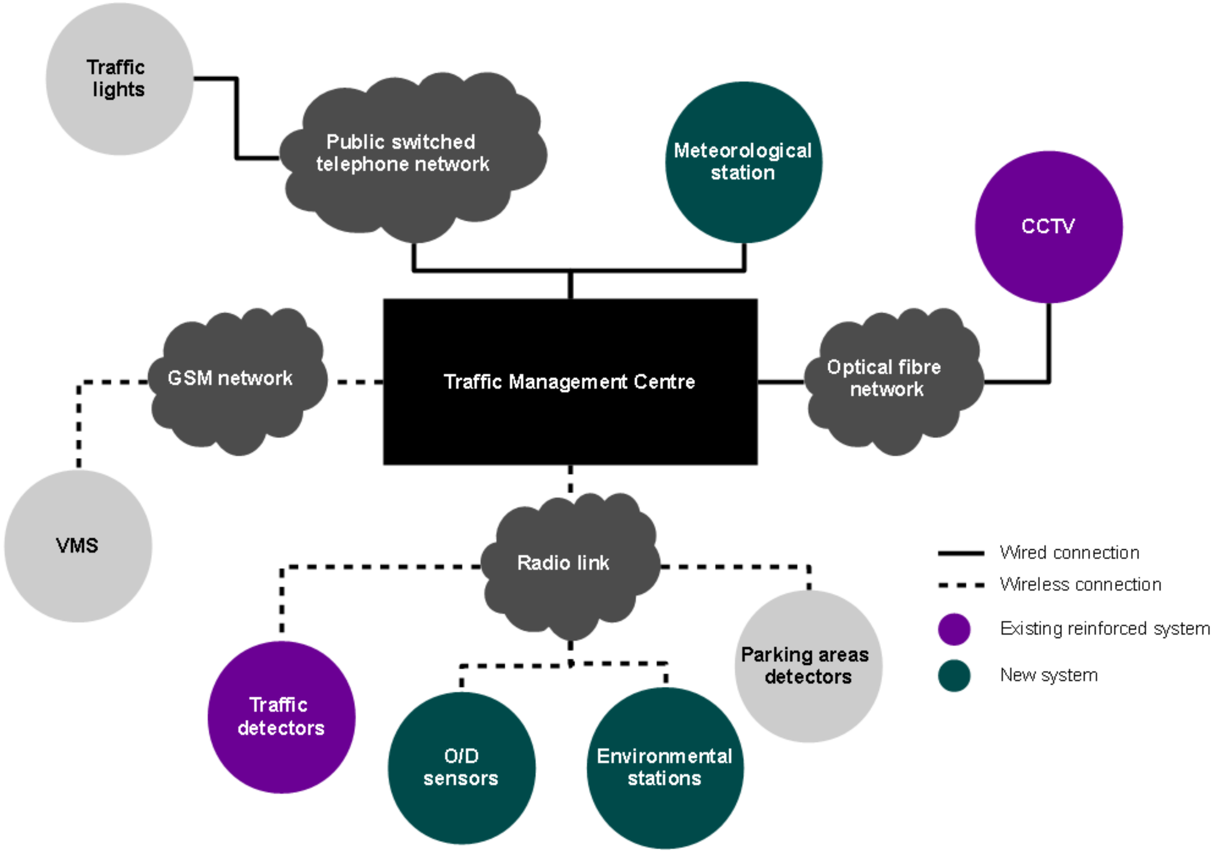


Figure 29: High-level architecture of the expanded TMC of Bolzano.

2.3 Environmental Monitoring system in the city of Bolzano

The air quality control within the urban area of Bolzano is a task which is directly accomplished by the Local Agency for Environment. This task is carried out by means of a network of fixed environmental stations, positioned at points in the city which suite well with the air quality measurements constraints defined by law.

Figure 30 provides a geographical indication about the positions of the different air quality monitoring stations, while Table 3 provides a complete overview of the set of air pollutants which are measured by each station. It is worth noting, that, on the base of the decisions taken in the last revision of the Air Quality Plan, the environmental station located in Verdi Square (already introduced in the INTEGREEN project proposal), very close to the city centre and highly exposed to traffic, is not available anymore, and has been recently definitely dismissed.

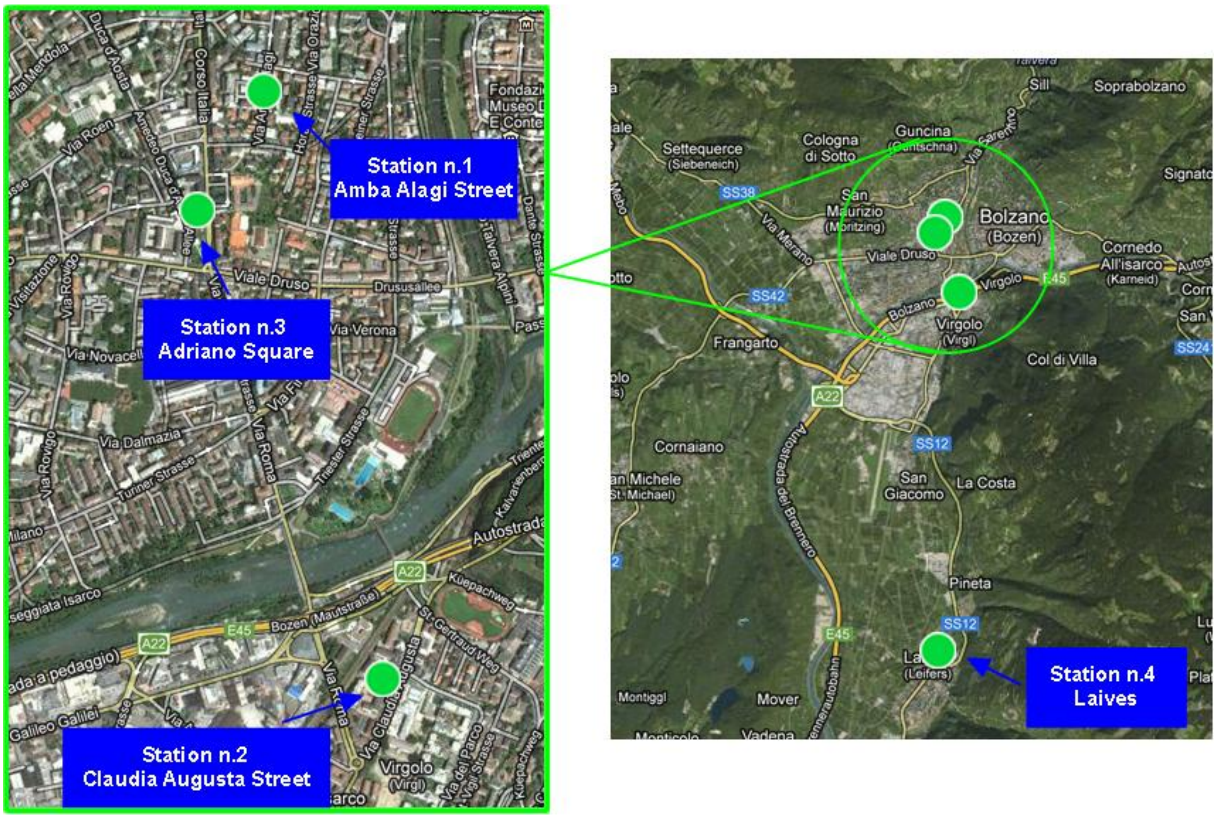


Figure 30: The network of fixed environmental stations for air quality monitoring in the city of Bolzano.

Air pollutants	Station n.1 - Amba Alagi Street (BZ1)	Station n.2 - Claudia Augusta Street (BZ4)	Station n.3 - Adriano Square (BZ5)	Station n.4 – Laives (LS1)
SO_2	YES	NO	NO*	NO
PM_{10}	NO	YES	YES	YES
$PM_{2.5}$	NO	YES	NO	YES
NO_2	YES	YES	YES	YES
CO	NO	NO	YES	NO
O_3	YES	NO	NO	YES
$C_6 H_6$	YES	NO	NO	NO
Heavy metals	NO	NO	YES	NO
B_aP	NO	NO	YES	NO
Meteorological parameters	Air temperature Solar irradiation	Air temperature Pressure	Air temperature Pressure	Air temperature Solar

	UVA/UVB sun rays Pressure Wind speed and direction Humidity Precipitation (type, intensity)	Humidity	Humidity Wind speed and direction	irradiation Pressure Wind speed and direction Humidity Precipitation (type, intensity)

** This air pollutant is not measured anymore since 2009.*

Table 3: Air quality- and meteorological parameters monitored by the fixed environmental stations.

Each station avails of automatic instruments for the continuous measurement of air pollutants and meteorological parameters. Further instruments are available for semi-automatic and manual measurements as well. The reference measurement methodologies that are considered for the different air pollutants are presented in Table 4.

Air pollutants	Measurement methodology
SO_2	UV fluorescence
$PM_{10} – PM_{2.5}$	β- rays attenuation
NO_2	chemiluminescence
CO	Non-Dispersive Infrared (NDIR) spectometry
O_3	UV Spectrophotometry
$C_6 H_6$	Gas Chromatograph – Photoionization Detector (GC-PID)

Table 4: Air quality parameters and adopted measurement methodology.

The remote stations are connected with the Regional Environmental Monitoring Centre through an ISDN network. Measured values are transmitted on an hourly basis to the Data Management Centre, which consists of (i) a Front-End which receives the data from the environmental stations and (ii) a Oracle® database which stores the records. Before the publication on the web, data are post-elaborated by a semi-automatic validation procedure, which consists of (i) a pre-validation step based on mathematical filters and (ii) a manual validation done by local experts. The whole system architecture is presented in Figure 31.

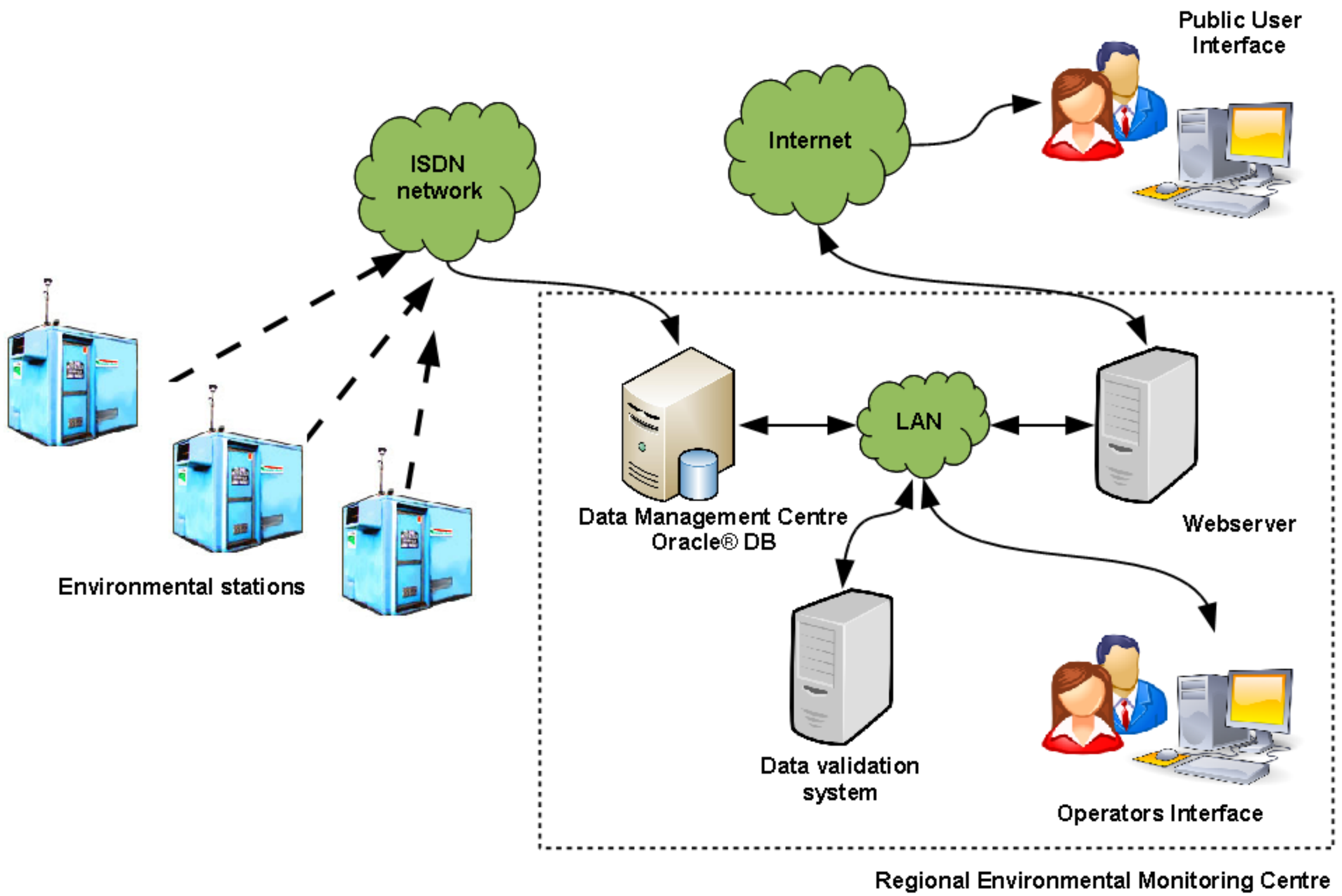
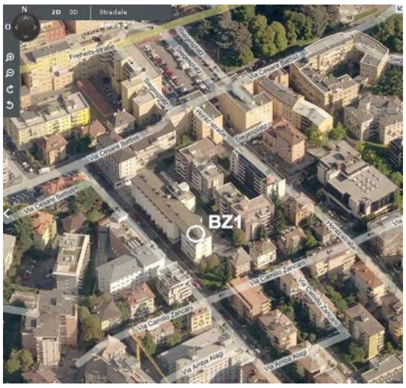


Figure 31: The environmental monitoring system architecture.

2.4.1 The station in Amba Alagi Street (BZ1)



The station BZ1 positioned in Amba Alagi Street is located in a residential district close to the city centre, with low exposure to traffic, at an altitude of 270 [m.s.l]. The station is destined primarily for the **measurement of ozone** (O_3) levels, but also monitors the levels of nitrogen dioxide (NO_2) and benzene (C_6H_6) for the protection of the human health. Sulphur dioxide (SO_2) is also monitored but only for local interest.

At present, all these parameters are monitored at a height of 25 [m] from the ground level, but a second station near the existing one capable to measure nitrogen dioxide, benzene and sulphur dioxide at a ground level is going to be introduced soon. Meteorological parameters are monitored as well, in particular: air temperature, solar irradiation, UVA/UVB sun rays, air pressure, wind speed and direction, humidity and type and intensity of precipitation.

2.4.2 The station in Claudia Augusta Street (BZ4)

The station in Claudia Augusta Street is located in a residential district close to the industrial area of the city, with **medium exposure to traffic**, at an altitude of 247 [m.s.l]. It is destined primarily for the measurement of the levels of nitrogen dioxide (NO_2), but also monitors the levels of particulate matter, both PM_{10} and $PM_{2.5}$.

It is considered not compliant with the existing measurement procedures defined by law, because of the surrounding trees, not sufficiently far from the station, which can significantly influence the measured values [11]. For this reason, the plan is to shift the station of about 10 [m] from the actual position, in order to remove this systematic noise. Meteorological parameters are monitored as well, in particular: air temperature, air pressure and humidity.

2.4.3 The station in Adriano Square (BZ5)

The station in Adriano Square is located in a residential district close to the city centre, with **high exposure to urban traffic**, at an altitude of 260 [m.s.l].

Because of its particular position (it is 5 [m] far from the roadway and 30 [m] far from one of the main crossroads of the city), it is destined primarily for the measurement of different air quality parameters, with the objective to evaluate the environmental impact produced by road traffic. It monitors the levels of nitrogen dioxide (NO_2), particulate matters (PM_{10}), benzo(a)pyrene (BaP), carbon monoxide (CO) and heavy metals (lead, arsenic, cadmium and nickel). It is fully compliant with the existing measurement procedures defined by law. Meteorological parameters are monitored as well, in particular: air temperature, air pressure, humidity and wind direction and speed.

2.4.4 The station in Laives

A fourth station (**Errore. L'origine riferimento non è stata trovata.** and **Errore. L'origine riferimento non è stata trovata.**) which might be of interest for the INTEGREEN project is the one located in the town of Laives, which is a small village in the peripheral area at the south of Bolzano. This station, positioned at a height of 230 [m.s.l], has however very low exposure to traffic – the distance from the nearest urban buildings and roads characterized by high traffic density is about 500 [m]. It monitors the levels of nitrogen dioxide (NO_2), particulate matters (PM_{10} and $PM_{2.5}$) and ozone (O_3). It is fully compliant with the existing measurement procedures defined by law. Meteorological parameters are monitored as well, in particular: air temperature, air pressure, humidity, wind direction and speed, type and intensity of precipitation and solar radiation.

2.4.5 Public web interface

Air pollution levels are shared with the final user through a public web interface [6]. For each of the stations of the regional network, the user has the possibility to get, in graphical form, a daily or monthly report of the mean air pollutant levels which have been measured (Figure 32). The values are presented in a graphical way so that a qualitative evaluation of the air quality status with respect to the upper bound values defined by law is immediately possible. In the case of monthly report, the published values are the mean daily values which refer to each day of the month; in the case of daily report, the published values are the mean values calculated on an hourly basis. The daily report graphics are neverthless available only for a subset of pollutants, and in particular: NO_2, O_3 and CO.

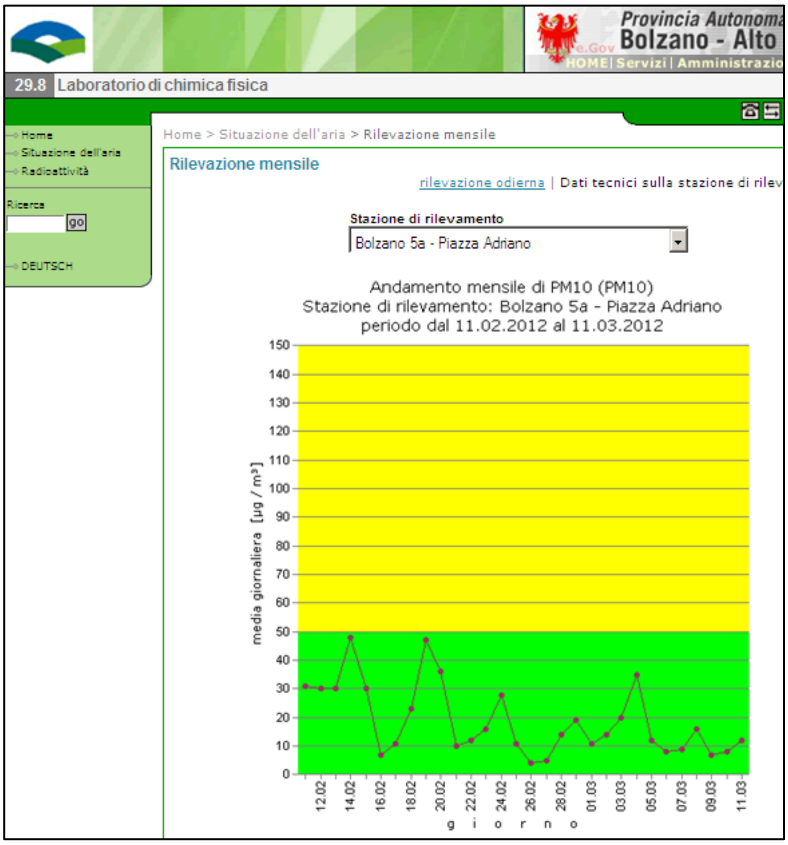


Figure 32: Public web interface with daily publication of measures of air quality parameters.

2.4 Baseline data, and preliminary measurement campaigns results

This paragraph provides an holistic overview of the baseline data, which is needed in order to calculate the environmental impact of the project, a task which is carried out in Action n.8, Task 8.2. The impact is evaluated in terms of both **air pollution**, i.e. chemical substances emitted by vehicular traffic that can cause direct problems to the health of human beings, and **greenhouse gases**, i.e. chemical substances which have an important role in the energy balance of the Earth and are responsible of the long-term alterations of the air temperature on the planet because of their capability to absorb the infrared radiation. The baseline data which is considered suitable for this kind of activity is summarized in Table 12.

Data class	Description	Data source
Air pollution	Periodic air quality assessment reports and comparison with reference indicators defined by law. Daily average of the main traffic-induced air pollutant levels (i.e. PM_{10} and NO_2) measured by stations BZ4 and BZ5 in the period September 2010 – August 2011 (i.e. a time interval of one year before the project start).	Local Agency for Environment
Air pollution	Study commissioned by Municipality of Bolzano to local company CISMA concluded in early 2010 which deepens the air pollution problems concerning NO_x pollutants [12]. The study identifies and quantifies main pollutant sources, calculated the produced emissions, and evaluates their impact on the city by means of a	Municipality of Bolzano, CISMA

	dispersion model.	
Greenhouse gases	Study commissioned by Municipality of Bolzano to local research center EURAC concluded in early 2010 which calculates the CO_2 emissions in the city and assesses the potential reduction impact of several long-term measures [13].	Municipality of Bolzano, EURAC research
Greenhouse gases	Targeted measurement campaigns aiming at empirically (i) quantifying the typical fuel consumptions and CO_2 emissions of vehicular travels in the city of Bolzano and (ii) determining the local weight of several transport-related inefficiency factors.	INTEGREEN project

Table 5: Baseline data set for the calculation of the environmental impact of the project.

2.4.1 Air pollution baseline data evaluation

Air pollutant levels for the years 2010 and 2011 are summarized in Table 7. The levels are compared to the reference indicators defined by law, reported in Table 6. The parameters exceeding these threshold values are highlighted in red colour.

Air pollutant	Indicator	Value	Description
PM_{10}	PM10_1	Daily average of 50 [µg/m^3]	Daily average can exceed the reference value at maximum 35 times/year
PM_{10}	PM10_2	Annual average of 40 [µg/m^3]	Annual average must be beyond the reference value
$PM_{2.5}$	PM2.5_1	Annual average of 25 [µg/m^3]	Annual average must be beyond the reference value
NO_2	NO2_1	Hourly average of 200 [µg/m^3]	Hourly average can exceed the reference value at maximum 18 times/year
NO_2	NO2_2	Annual average of 40 [µg/m^3]	Annual average must be beyond the reference value

Table 6: Reference air pollutant indicators defined by the Italian law.

Indicator	Unit of measurement	Station	2010	2011
PM10_1	Numbers of exceeding days	BZ4	15	18
		BZ5	11	12
PM10_2	Annual average	BZ4	23	26
		BZ5	19	19
PM2.5_1	Annual	BZ4	14	17

	average			
		BZ5	15	15
NO2_1	Maximum hourly average	BZ1	113	109
		BZ4	132	147
		BZ5	130	138
NO2_2	Annual average	BZ1	33,3	33,1
		BZ4	44,2	46,4
		BZ5	39,8	42,2

Table 7: Air pollutant levels in 2010 and 2011 compared to reference indicators.

The PM_{10} levels measured by stations BZ4 and BZ5 within the reference period September 2010 – August 2011 are plotted in Figure 33. It is worth noting the similar trends obtained by comparing the measurements obtained by the two stations (the correlation coefficient is equal to 96,7%), and the significant increase in the concentration levels during the winter season as a consequence of the emissions caused by heating devices.

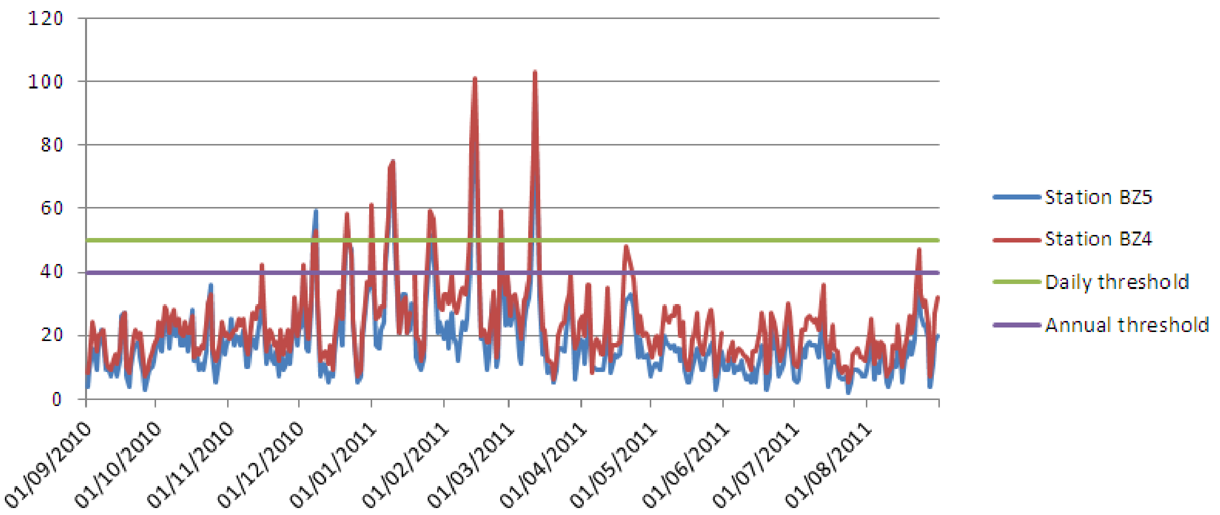


Figure 33:The PM_{10} levels in the reference period September 2010 – August 2011.

The number of days in which the daily average exceeds the reference threshold of indicator PM10_1 is 14 and 19 for stations BZ4 and BZ5, respectively. Figure 43 points out not only when these situations have occurred, but also highlights the days which are potential contributors for increasing the annual average (indicator PM10_2). Finally, in Figure 35 are plotted the averages calculated on a monthly basis (i.e. the mean of the daily averages measured in a specific month), in order to determine a stricter relationship between this air pollutant and a specific month of the year.

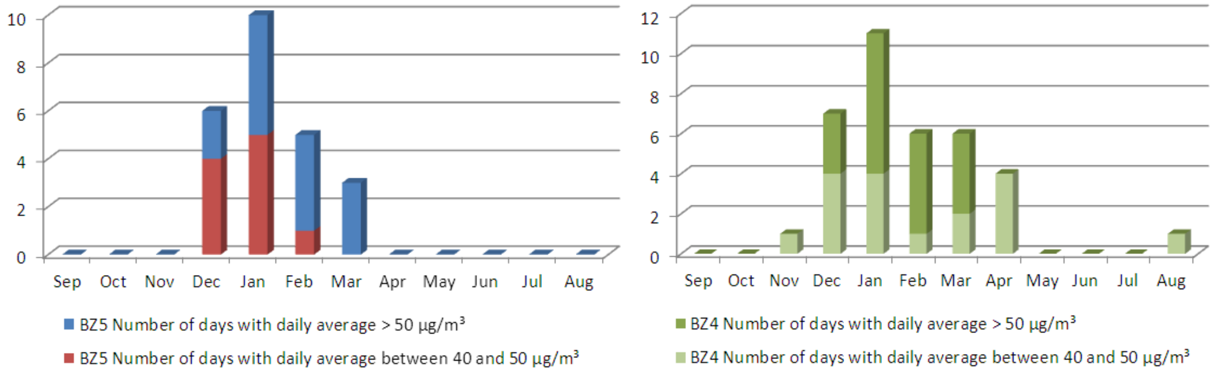


Figure 34:The distribution of PM_{10} exceeding days during the reference period September 2010 – August 2011.

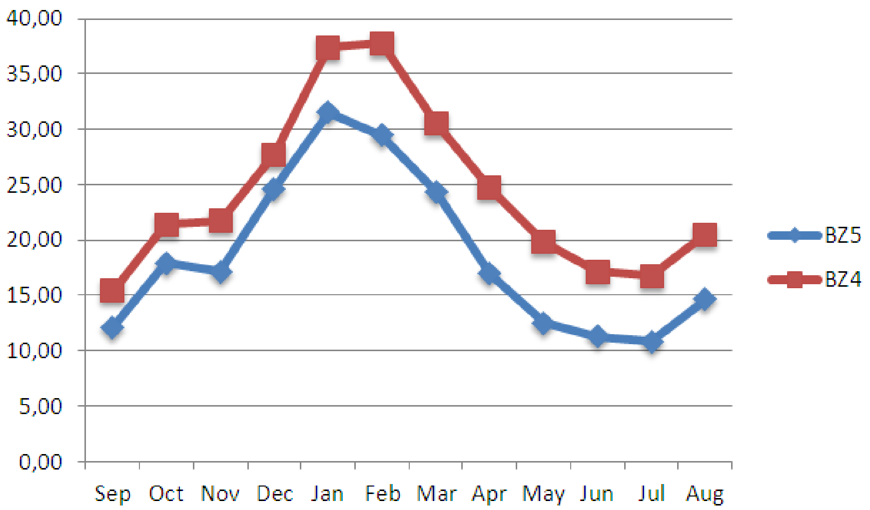


Figure 35: The monthly averages of PM_{10} in the reference period September 2010 – August 2011.

In Figure 36 it is possible to visualize the values measured for air pollutant NO_2. In this case, only the reference threshold of annual average indicator NO2_2 is considered.

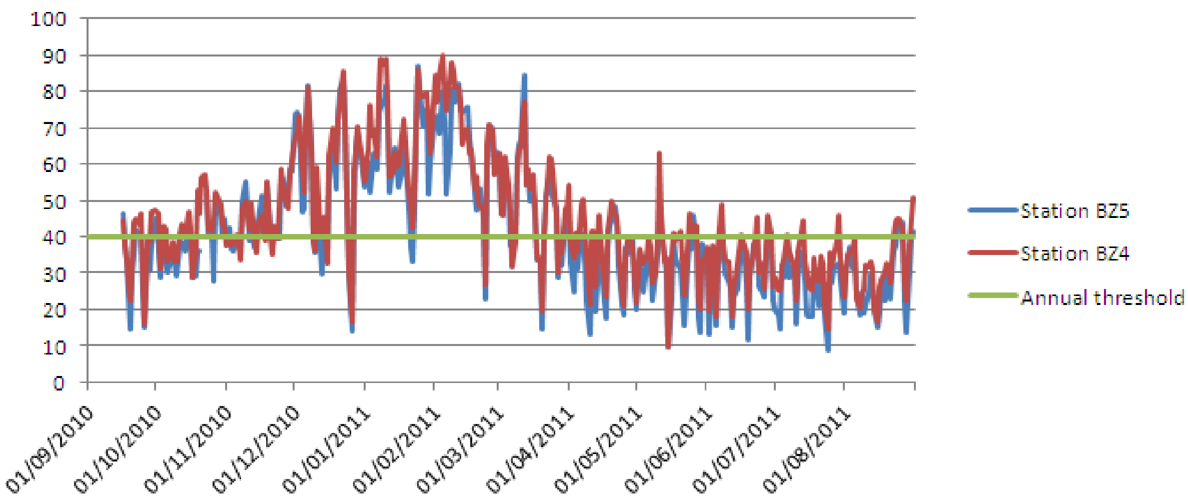
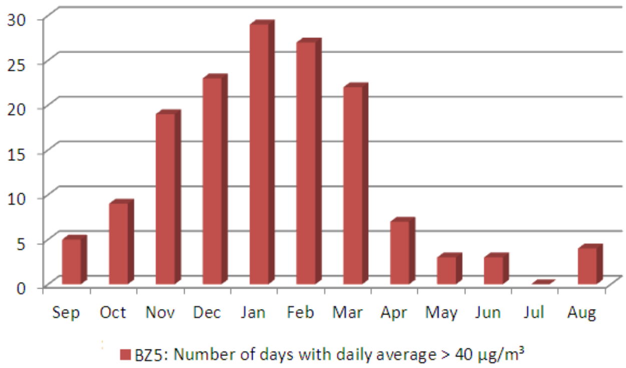


Figure 36:The NO_2 levels in the reference period September 2010 – August 2011.

The pattern is similar to PM_{10} (with a correlation coefficient of 96,0%) but in this case fewer peak values in the winter season are noticeable. The diagram clearly shows the concern about this air pollutant, as confirmed by the comparison with the annual threshold. The number of days which exceed this reference value are 151 and 194 for stations BZ4 and BZ5, respectively, and distributed as illustrated in Figure 37. If the indicator NO2_2 is applied on a monthly basis, there are many of them which would exceed this reference threshold, as presented in Figure 38.



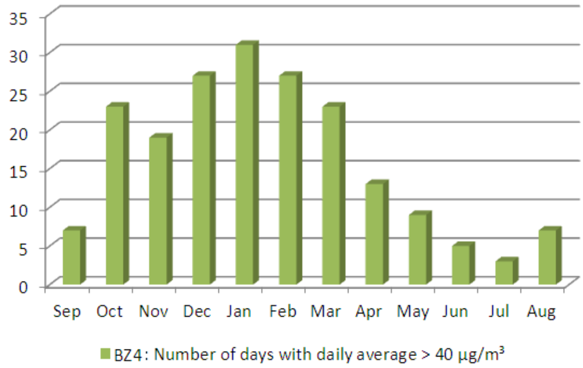


Figure 37:The distribution of days where NO_2 values exceed annual threshold during the reference period September 2010 – August 2011.

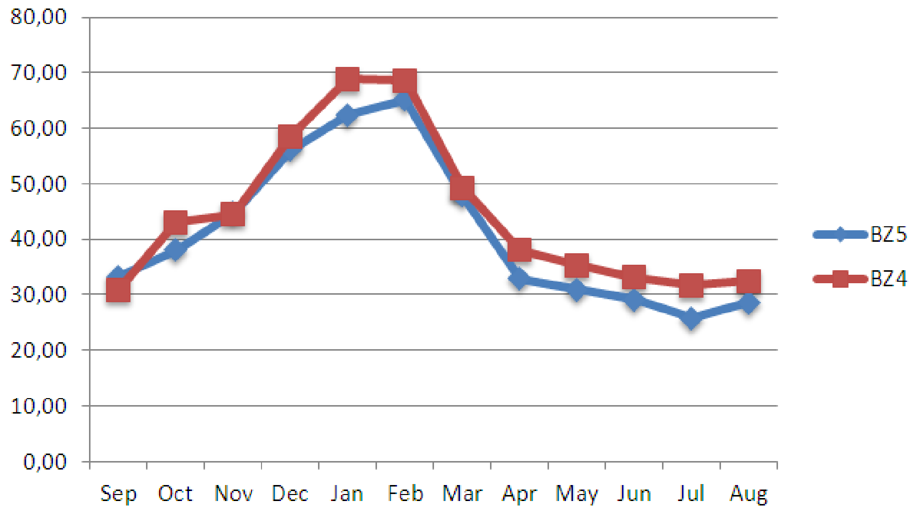


Figure 38: The monthly averages of NO_2 in the reference period September 2010 – August 2011.

It is finally worth noting that all these baseline data values must be analysed for comparisons with future project years in correlation with the meteorological conditions, and in particular with the levels of precipitation registered during the period of interest. The reference scatterplots are illustrated in Figure 39 and Figure 40, where on the x-axis are plotted the daily average of the reference air pollutant and on the y-axis the total amount of precipitation fallen during that day. The air pollution measurements refer to station BZ4.

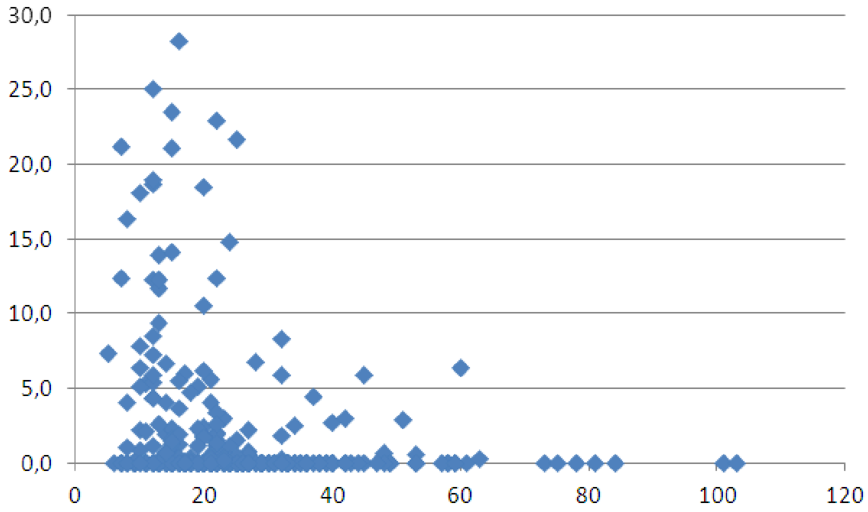


Figure 39: PM_{10} and precipitation levels scatterplot in the reference period September 2010 – August 2011.

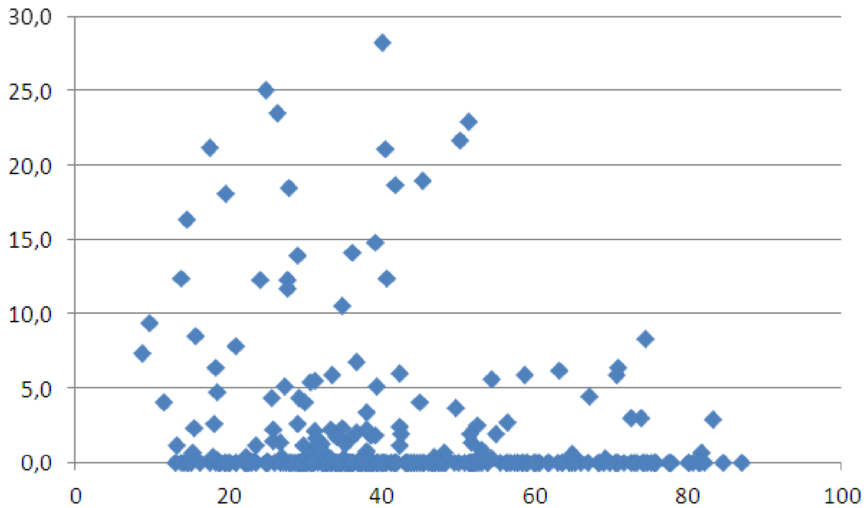


Figure 40: NO_2 and precipitation levels scatterplot in the reference period September 2010 – August 2011.

The exceeding of the boundary values defined by law of NO_2 air pollutant, in particular concerning indicator NO2_2, determined the necessity, by the Local Agency for the Environment, to define a return plan which is able to bring back NO_2 levels under this threshold before 2015. In order to properly organize it, it is has been necessary to have a deeper understanding of the different emission sources and their associated contribution to this air pollution problem. A study commissioned to CISMA, a local start-up company incubated in TIS innovation park, accomplished this task, and early analysed possible return scenarios by means of pollutants dispersion models [12], following the methodology which is illustrated in Figure 41.

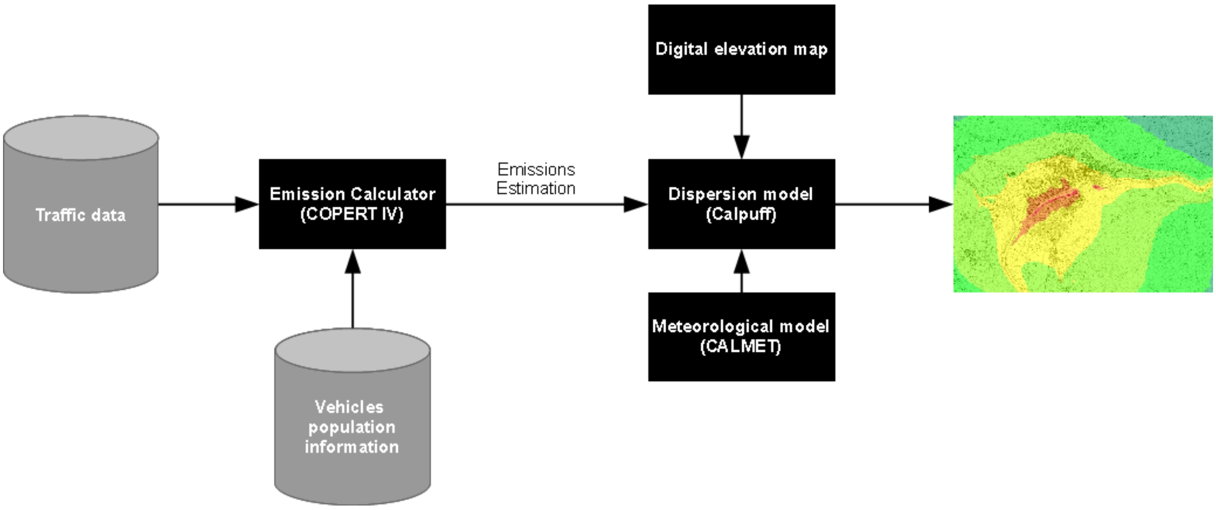


Figure 41: The methodology adopted by CISMA in its NO_2 evaluation study for the city of Bolzano.

The study made in particular an estimation of the contribution on NO_2 concentration levels caused by road traffic, divided by (i) **linear sources**, which include the A22 highway traffic and the main urban roads; and (ii) **spread sources**, which are streets of minor traffic but very near to the residential buildings. Because of the nature of these sources, which are localized at low altitude, the area of the environmental impact is spatially very limited. The emissions generated by road vehicular traffic were calculated through the **COPERT IV** software (*Computer Programme to calculate Emissions from Road Transport*) [14], which is a software whose development is coordinated by the European Environment Agency (EEA). COPERT IV allows to estimate the emissions of several air pollutants, such as NO_2, in particular as a function of:

- the circulating vehicle fleet, characterized by:
  - ✓ total number of vehicles;
  - ✓ registration year;
  - ✓ engine capacity (for passenger cars);
  - ✓ weight (for duty vehicles);
- average speed and Vehicular Kilometres Travelled (VKT);
- emission factors;
- fuel type.

Except for the emission factors, which are tabulated values associated to each category of vehicle available in the literature and already uploaded in the software, the other parameters can be set by the user by considering national and regional vehicle fleets data and through specific analysis of the available local traffic patterns. The study took in consideration values referring to year 2005, with specific hypothesis of evolution of the above parameters based on energetic and economic factors, according to the GAINS (*Greenhouse Gas – Air Pollution Interactions Synergies*) model [10]. It is worth noting that in the model an average speed value has been taken in consideration, which is representative of a specific traffic-related emission source. In this study, the effect produced by congestion phenomena (low speed vehicles), in which air pollutants emissions tend to rapidly diverge, are therefore not taken into account.

According to the results of this study, the main NO_2 road traffic emission sources are **heavy duty vehicles** and **passenger cars**, while light duty vehicles and motorcycles provide a less relevant contribution (Figure 42). For the sake of completeness, a similar estimation was performed for PM_{10}. In this case, the contribution of passenger cars is higher, while heavy duty vehicles have a less predominant factor. Even light duty vehicles and motorcycles produce a higher contribution than in the NO_2 case (Figure 43).

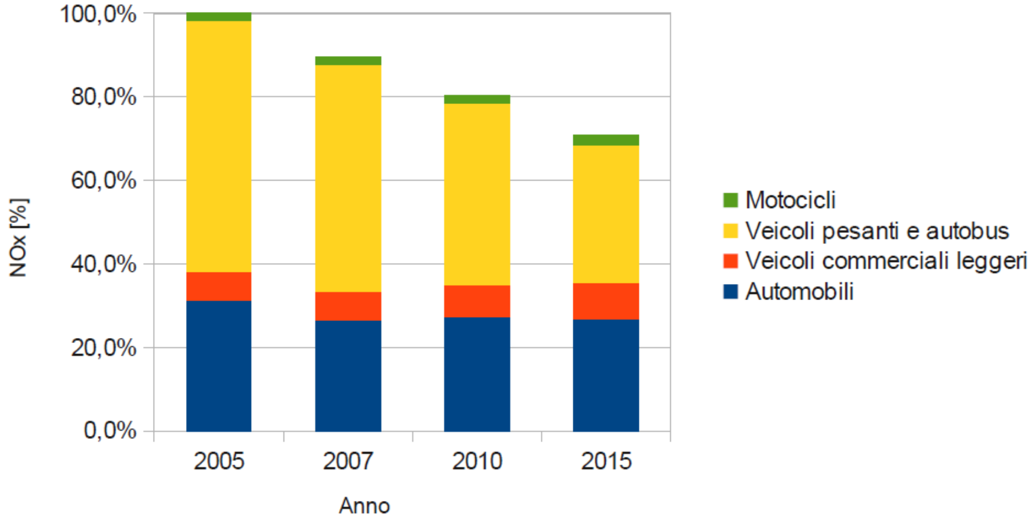


Figure 42: The NO_2 emissions generated by traffic per vehicle type in the city of Bolzano and the expected trend [12].

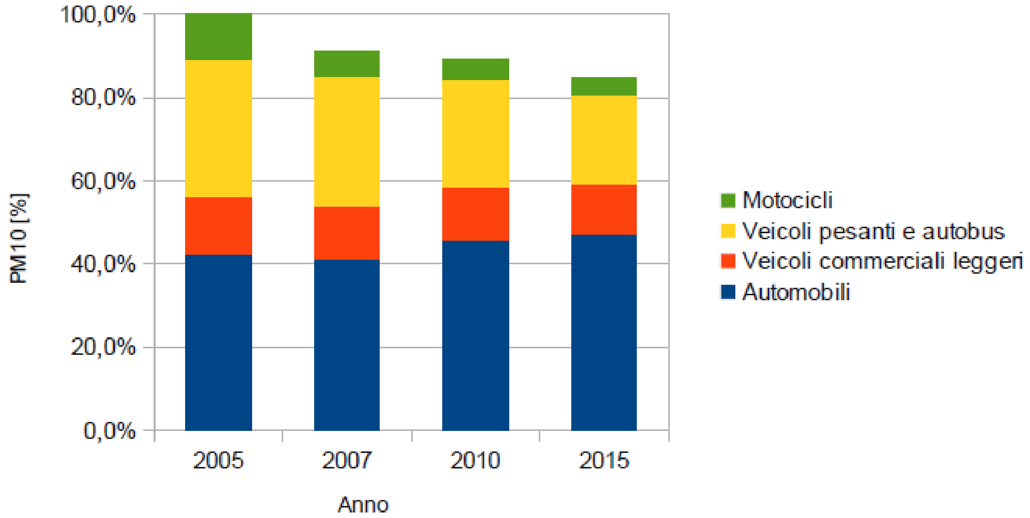


Figure 43: The PM_{10} emissions generated by traffic per vehicle type in the city of Bolzano and the expected trend [12].

Another important consideration was that the most important emission source in 2007 was **linear traffic**: both A22 highway and main urban roads were responsible of about 406 [tons/year] of NO_2 emissions, which is equivalent of about 42% of the whole NO_2 emissions (Table 8). However, spread traffic is a considerable source too (17%), as a clear assessment of the local role of urban road transports on the emissions of this air pollutant. The interesting data for the INTEGREEN project, is that **urban traffic in the Municipality of Bolzano is totally the main NO_2 emission source (34%)**.

Emission source	NO_x emission [tons/year]	%
Industry	152	16%
Linear traffic (A22 highway)	241	25%
Linear traffic (urban main roads)	165	17%
Spread traffic	163	17%
Heating and commercial sector	242	25%
TOTAL	963	100%

Table 8:Calculation of NOx emissions as a function of the heterogeneous emissions sources [12] .

A dispersion model of NO_2 was finally considered in order to understand how emitted NO_2 are carried away and diluted in the scenario of interest. Because of the particular topology and meteorological characteristics of the city of Bolzano, the chosen dispersion model was CALPUFF, commercialized by Earth Tech Inc., which can be integrated with the meteorological model CALMET [16]. Providing the calculated emissions to the dispersion model, NO_2 concentration maps were produced. In this way, it was possible to identify the area of the city which are more exposed to NO_2 concentration levels and thus more at risk (Figure 44).

2.4.2 Greenhouse gases baseline data evaluation

A study commissioned to EURAC research, the European Academy located in Bolzano, performed in 2010, under the supervision of the Municipality of Bolzano, an evaluation study on the global CO_2 emissions generated by the city in the different interest sectors, including an estimation of their possible reduction through specific intervention lines and policies.

One of the main results of this study has been to quantify and compare the different emission sources, which are transports and the production chain of thermal and electrical energy. As indicated in the diagram of Figure 45, transports in Bolzano are one of the main CO_2 emission sources (ca 31% of the whole emissions), responsible in a year for about 3.0 tons per inhabitant, which is equivalent of about 272 [ktons/year].

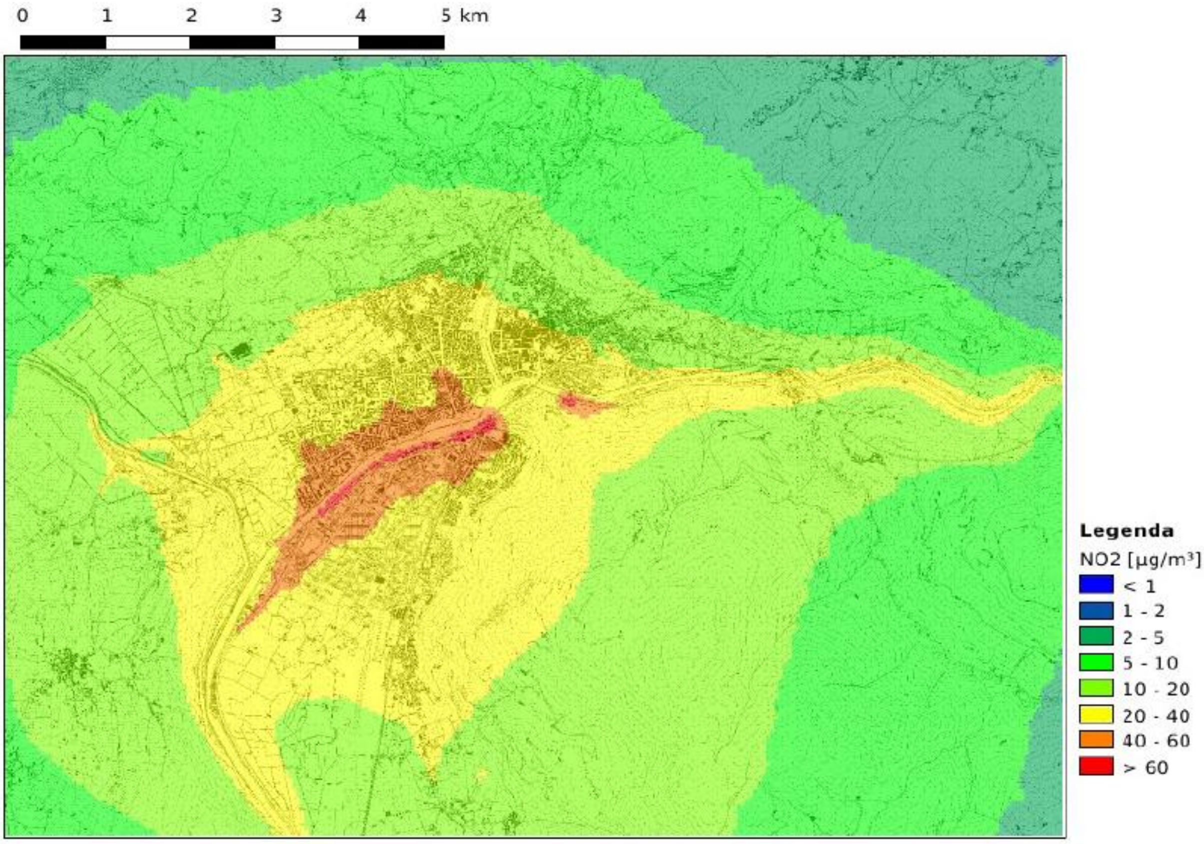


Figure 44: The NO_2 concentration map based on emissions estimation and CALPUFF simulations [12].

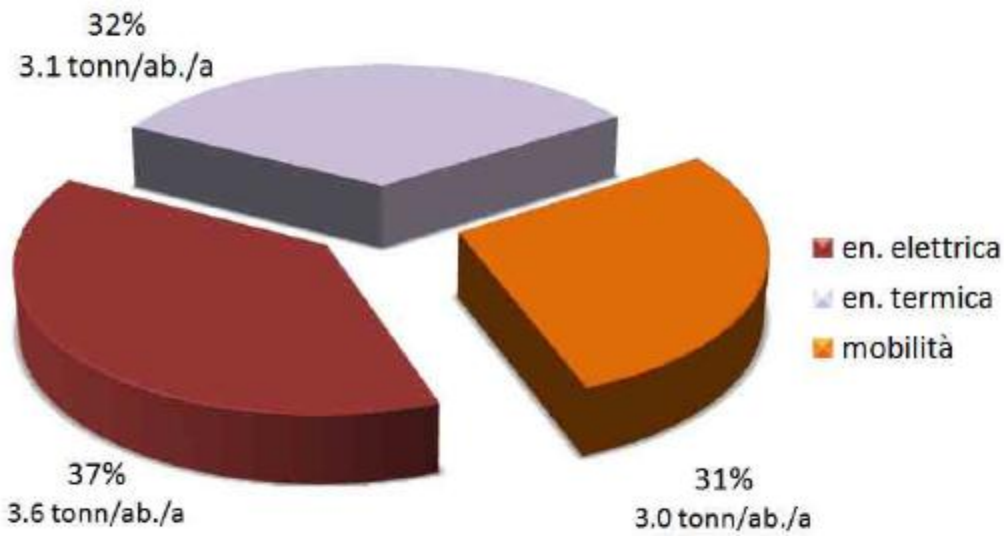


Figure 45: CO_2 emissions estimation in year 2007 for the city of Bolzano [17].

The analysis has put in clear evidence that there are significant margins for reducing the today's amounts of CO_2 emissions in Bolzano. **The city of Bolzano has defined a very ambitious target to reduce emissions in 2030 from the starting value of 9.7 tons per inhabitant a year up to 2.0**. In the transport sector, in particular, most of passengers and goods transports are carried out on the road, and not on the rail. The consequence for that is the necessity of significant investments in new transport infrastructure, as described in detail in the already aforementioned Urban Mobility Plan 2020 [5].

A more detailed overview of the transport sector emission sources puts in evidence two different aspects:

- as far as **passengers transports** concern, the main source is represented by private road traffic generated by cars (Figure 46). The contribution of public transports is very limited if compared to the private one: emissions generated by motorcycles is even higher;
- as far as **goods transports** concern, there is a clear imbalance in favour of road traffic. Road goods transport is responsible alone for about 50% of all transport-related CO_2 emissions (Figure 47).

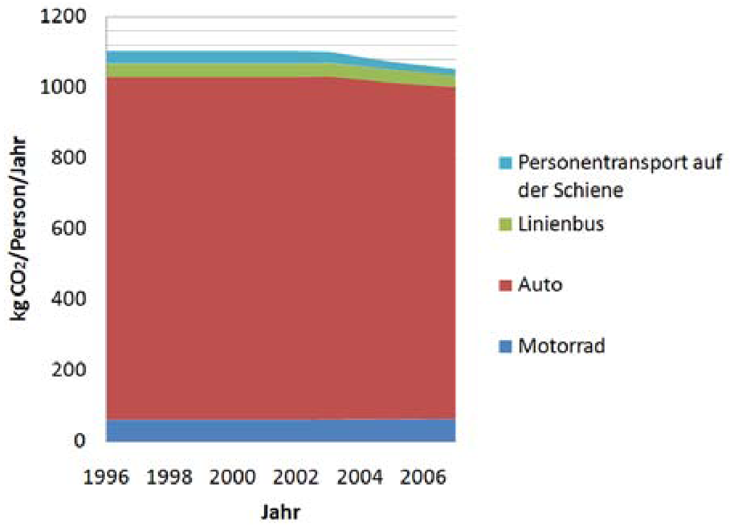


Figure 46: CO_2 emissions produced by passenger road transport means in the city of Bolzano [17].

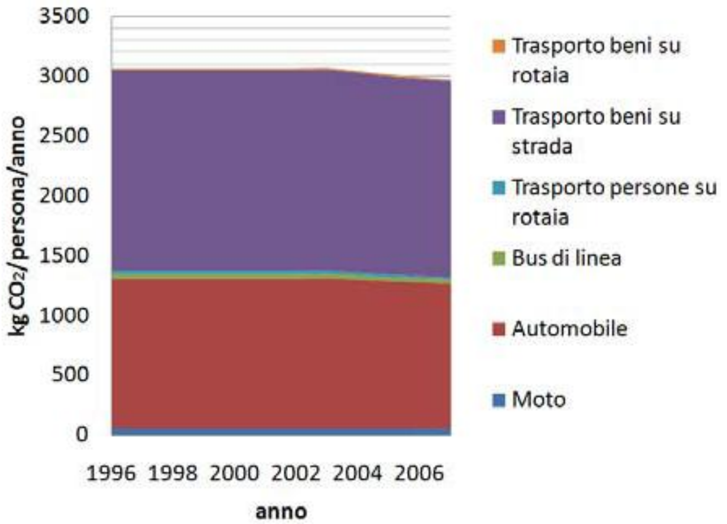


Figure 47: CO_2 emissions produced by passenger and goods transport means in the city of Bolzano [13].

The CO_2 emissions calculation availed on the ECO2Regio software [14], which is an online tool that allows to make an approximation of the CO_2 emissions on the base of the methodologies and calculation factors provided by the Intergovernmental Platform on Climate Change (IPCC), in particular in [19]. Input data that are peculiar for the area of interest are of course necessary. The analysis has taken into account only the CO_2 emissions produced by the use of fossil fuels, neglecting the contribution of natural processes. The adopted methodology is based on:

- a **causality approach**, which considers not only the "final energy" contribution, but all fuel consumption which is needed in the production chain (the so called *life cycle assessment* - LCA);
- a **bottom-up approach**, which makes the calculation of the CO_2 emissions on the base of local traffic and mobility data, and in particular on:
    - private road traffic passengers flows (P), evaluated in terms of [passenger*km/year], calculated as:

      $$P = N_v \cdot F_v \cdot D \cdot F_a \quad (1)$$

      where N_v is the total number of registered vehicles circulating in the city, F_v is an occupancy vehicle factor, which expresses, on average, the number of passengers transported by each vehicle, D is the annual distance covered on average by a vehicle, and F_a is a correction factor which takes into account the specific modal split of Bolzano compared to the national one.
    - road traffic goods flows (G), evaluated in terms of [vehicle*km/year], calculated as:

      $$G = {N_v}^c \cdot D^c \quad (2)$$

      where ${N_v}^c$ is the total number of registered commercial vehicles circulating in the city (${N_v}^c < N_v$) and D^c is the annual distance covered on average by a commercial vehicle.

On the base of these parameters, it is possible to calculate the CO_2 emissions value ${E_{CO_2}}^{LCA}$ (expressed in [tons/year]) produced by these traffic components. Regarding private road traffic passengers flows, the following calculations apply:

$${E_{CO_2}}^{LCA}\ P \ = P \cdot {C_S}^P \cdot {F_{LCA}}^P \quad (3)$$

where ${C_S}^P$ and ${F_{LCA}}^P$ are the corresponding specific consumption - (in [Joule/passengers*km]) and the LCA emissions factor provided by IPCC (in [tons/Watt*hour]), respectively.

For road traffic goods flows, a similar calculation is applied:

$${E_{CO_2}}^{LCA}\ G \ = P \cdot {C_S}^G \cdot {F_{LCA}}^G \quad (4)$$

Please note that the model does not take into account specific traffic regulation policies, like for example traffic limitations during the winter season. Moreover, the specific consumption parameters refer to data which are based on national values, and do not really take into account the vehicular population that is specific for the area of study.

Unfortunately, the study carried out by EURAC does not take in consideration the impact of **microscopic factors** on the amount of CO_2 emissions produced during a vehicular travel. This aspect is however particularly important for the objectives of the INTEGREEN project, and needs to be a priori evaluated in order to estimate the inefficiency level that can be addressed by the project. For this reason, a dedicated measurement campaign was organized in May 2012 with the intention to start to empirically quantify the impact of the different microscopic factors on the CO_2 emissions during a vehicular trip, and in particular to assess the following points:

- **traffic conditions factor**: what is the impact if the same trip is performed in presence of different traffic conditions? And what is the impact of bad weather conditions?
- **road peculiarities**: what is the impact produced by different traffic control policies, i.e. by crossing traffic intersections with different priorities?
- **driving style factor**: what is the impact if eco-driving rules are taken into account?
- **navigation factor**: what is the impact of the route choice, given the same origin-destination couple (O/D)?

A reference urban test route of about 8.8 [km] was considered for these tests. The route, defined as a ring, was determined in order to sufficiently take into account the peculiarities of the local urban road infrastructure and traffic (Figure 48). Some of the most congested urban roads are considered in the path. Four checkpoints (including the origin/destination one) were defined as well in order to have the possibility to characterize the peculiarity of four specific sections of the test route[13]. It is worth noting that for the assessment of the navigation factor, two different routes of total length 6,4 and 4,1 [km], respectively, were considered over the same O/D couple, as illustrated in Figure 49. The road peculiarities of the four test route sections as well as of these two “navigation” paths are presented in **Errore. L'origine riferimento non è stata trovata.**.

Section	Traffic lights	Roundabouts	TOTAL
Section n.1	8	4	12
Section n.2	8	0	8
Section n.3	3	3	6

[13] Section n.1 includes a round on Pacinotti Street and Siemens Street before to take Righi Street in direction Resia Street. Section n.4 reaches Siemens Street directly from Volta street, without passing from Pacinotti Street.

Section n.4	2	4	6
TOTAL	21	11	32
Navigation path n.1	19	4	23
Navigation path n.2	10	1	11

Table 9: Peculiarities of the test route chosen for the local assessment of the impact of microscopic factors on CO2 emissions.

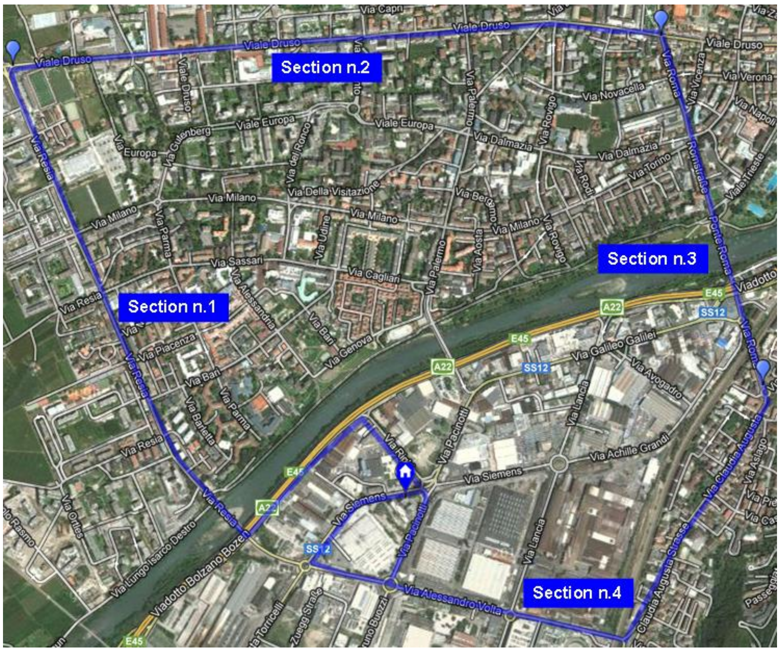


Figure 48: The test route for the local assessment of the impact of microscopic factors on CO_2 emissions.

Figure 49: The test route for the local assessment of the impact of the navigation factor on CO_2 emissions.

A naturalistic driving approach was chosen in order to carry out these tests [20]. The test route was driven by the same driver by means of the same car for twelve times during three days sessions in different traffic conditions (i.e. peak hour or standard) and by means of different driving styles, defined as follows:

- "**normal**": intended to be the naturalistic driving behavior of the driver;
- "**eco-driving**": considered the optimization of the "normal" driving style by means of the specific instructions provided by a coach during the trip phase;
- "**aggressive**": considered to be the case in which it was told to the driver to reach the destination in the shortest time but without reducing the safety level of the trip and of course by properly respecting the existing traffic laws (e.g. speed limits).

The meteorological variable was considered as well, since half of the tests (i.e. the ones carried out on 21/05) were carried out during bad weather conditions. The data related to each trip were saved by the on-board unit of the car, the Blue&Me system commercialized by FIAT. Collected data were then analyzed and compared by means of the eco:Drive software, which is a well-known tool for improving the driving efficiency of FIAT vehicles drivers. It is worth noting that all test sessions were performed with the air conditioning off, but with the start-stop system in function.

The main results for each test session are summarized in Table 10. The CO_2 emissions are calculated by multiplying the measured fuel consumption with a certain emission factor, which must be selected on the base of the fuel type. During the test sessions, a vehicle fueled by standard gasoline was considered, and therefore a constant **emission factor of 2,380 [kg/L]** was applied.

The data shows how all the analyzed microscopic factors can significantly influence the environmental impact of a trip covering the same route but performed under different conditions. The optimum case is probably the one registered at test session 5/2 under eco-driving mode and in free-flow traffic, which produced 1.309 [Kg] of CO_2, with a very limited number of stop&go (7) but even with a rather low travel time (00.18.40), as a consequence of a very reduced delay effect provided by the peculiarities of the road (i.e. the traffic lights and roundabouts). On the other side, the worst case can be considered test session 1/2, performed with an aggressive driving style and carried out during a peak time amplified by bad weather conditions. In this case, the environmental impact has been of

2.808 [Kg], with a very significant increase of both travel time and number of stop&go.

Test session ID	Day	Start Time	Travel Time	Traffic Conditions	Driving Style	Fuel consumption	CO_2 emissions	Number of Stop&Go
Test 1/1	15/05	07:47	00.24.28	Peak hour	Eco-driving	0,604 [L]	1.438 [Kg]	23
Test 2/1	15/05	08:13	00.20.43	Peak hour	Aggressive	0,764 [L]	1,818 [Kg]	21
Test 3/1	15/05	12.30	00.17.35	Standard	Normal	0,566 [L]	1,347 [Kg]	10
Test 4/1	16/05	14.37	00.21.05	Standard	Eco-driving	0,566 [L]	1,347 [Kg]	15
Test 5/1	16/05	15.00	00.17.50	Standard	Aggressive	0,758 [L]	1,804 [Kg]	20
Test 6/1	16/05	18.17	00.24.05	Peak hour	Normal	0,703 [L]	1,673 [Kg]	27
Test 1/2	21/05	07.57	00.35.30	Peak hour	Aggressive	1,18 [L]	2,808 [Kg]	61
Test 2/2	21/05	08.34	00.22.45	Peak hour	Eco-driving	0,62 [L]	1,476 [Kg]	19
Test 3/2	21/05	12.45	00.20.05	Standard	Normal	0,668 [L]	1,590 [Kg]	12
Test 4/2	21/05	14.32	00.19.10	Standard	Aggressive	0,862 [L]	2,052 [Kg]	14
Test 5/2	21/05	14.54	00.18.40	Standard	Eco-driving	0,55 [L]	1,309 [Kg]	7
Test 6/2	21/05	18.53	00.29.05	Peak hour	Normal	0,734 [L]	1,747 [Kg]	30

Table 10: The results of the baseline test sessions for the local assessment of the impact of microscopic factors on CO_2 emissions.

More details about the nature and the geographical position of the stop&go registered for each test session are reported in Figure 50. From just a qualitative evaluation of the patterns, it is possible to assess how both traffic and road peculiarities factors can occasionally determine a significant increase in the number of stop&go, even if in some cases amplified by the aggressive driving style adopted by the driver. The preliminary assessment of the impact produced by the microscopic factors under study can be summarized as follows.

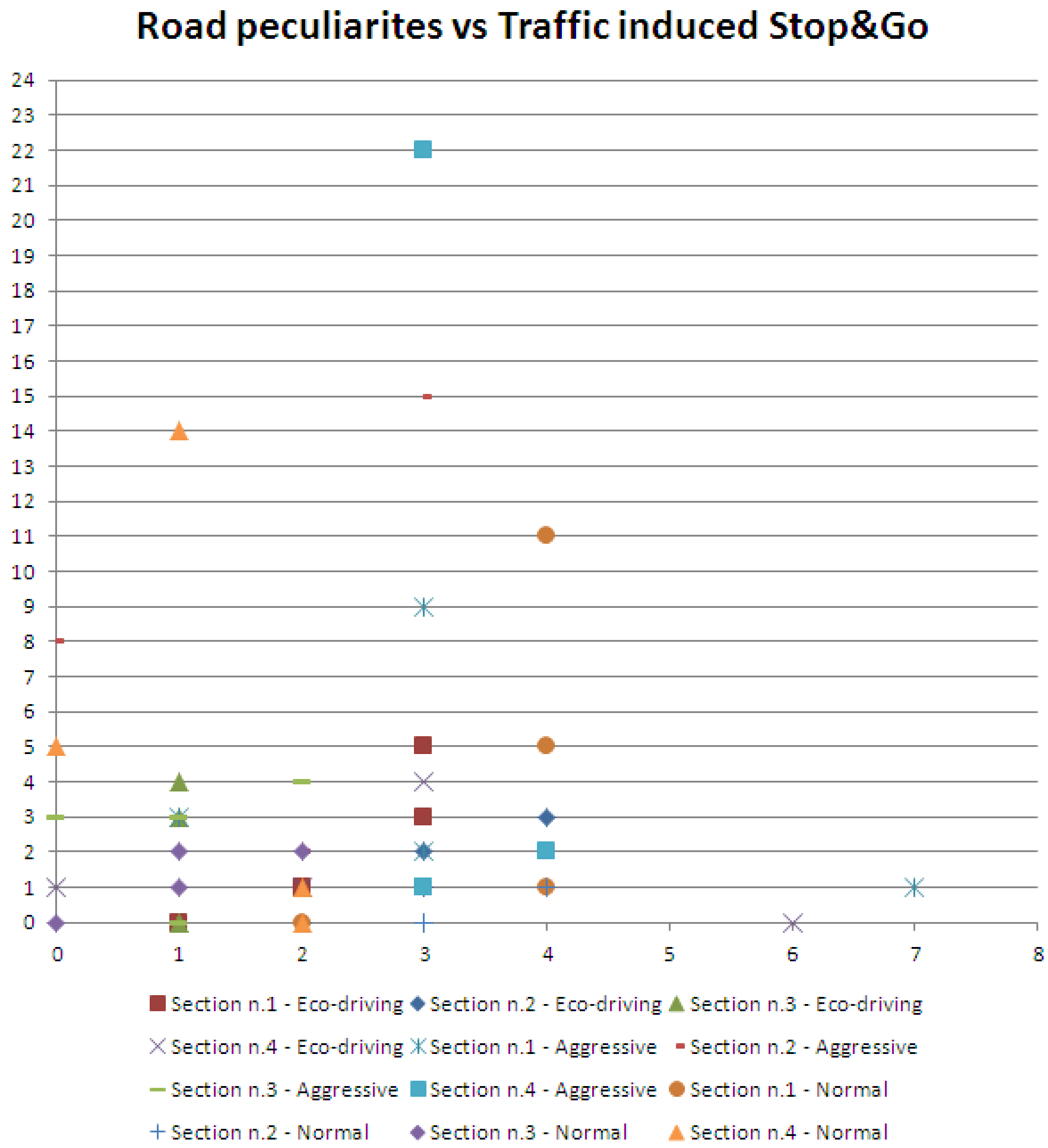


Figure 50: The empirical stop&go profiles for each section of the test route.

Traffic conditions and road peculiarities factors. Figure 51 graphically illustrates the amount of CO_2 emission and the correspondent travel time of each test session, performed in different times of the day. The horizontal distribution of the patterns is mainly influenced by the driving style factor, while the vertical distribution is mainly controlled by traffic and road peculiarities. In order to get a first raw estimation of the local impact produced by traffic conditions and road peculiarities, the test sessions under aggressive driving mode are excluded from this analysis, since this factor may probably be the dominant one.

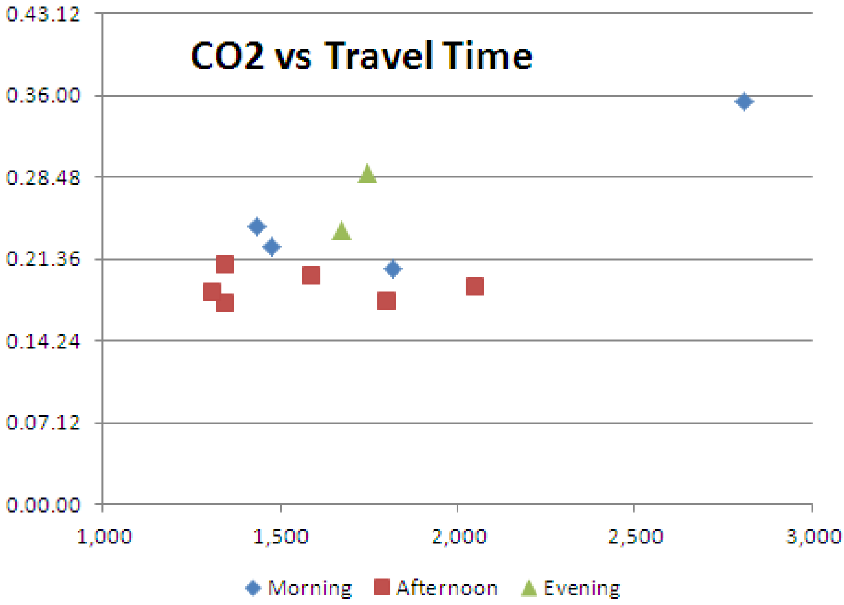


Figure 51: CO_2 emissions compared to travel times registered at different times of the day.

Figure 52 illustrates the distribution of the patterns of interest. In normal driving conditions, patterns registered during peak hours and in free-flow traffic conditions demonstrate that the correspondent environmental impact can be quantified to be under 30%, while in eco-driving conditions the optimized driving behavior can reduce the impact of these factors under 15%. Bad weather conditions have the effect to further increase the congestion level of some main routes in the cities, in particular during peak hours, and thus to amplify this impact.

The impact of traffic lights factor can be estimated by comparing test session 3/1 with test session 3/2, when two more stop&go were registered as a consequence of a red light phase in correspondence of as much traffic light intersections. The obtained result is 18%, a value which is however induced by the different spatial distribution of stop&go. In order to better determine this aspect, it is thus recommended to repeat this kind of measurements by considering just a localized set of networked traffic light intersections.

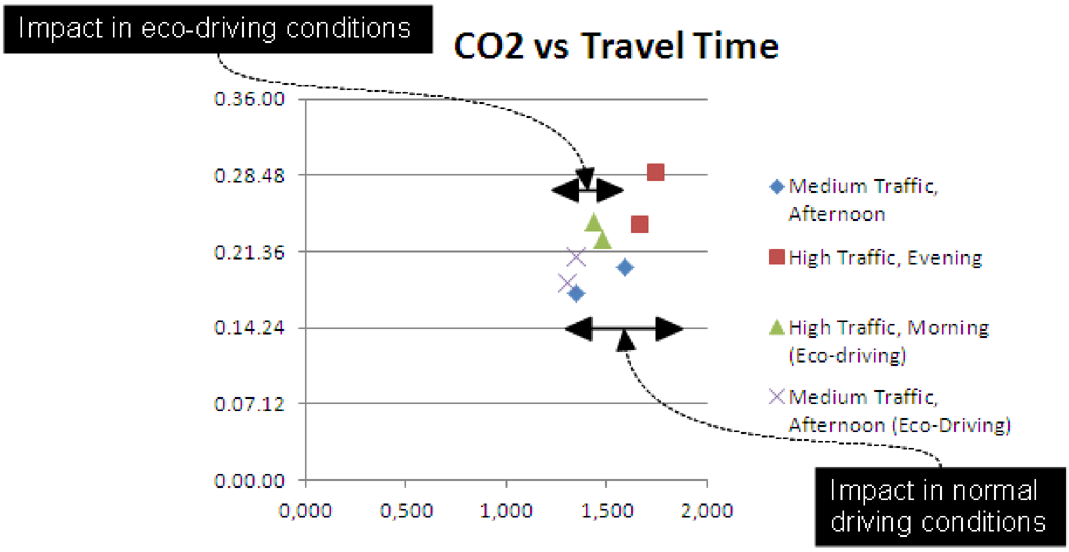


Figure 52: CO_2 emissions compared to travel times registered at different times of the day under eco-driving or normal driving conditions.

Driving style factor. Figure 53 graphically illustrates the amount of CO_2 emission and the correspondent travel time of each test session, performed under different driving conditions. In conditions of standard traffic conditions, the CO_2 emissions reduction when an eco-driving style is adopted can be quantified to be under 20% if compared to a normal driving profile, and be in the order of 40-50% if the comparison is made with an aggressive driving profile. These values can vary as a function of the stop&go that can be of course induced by traffic and road peculiarities; under eco-driving conditions the driving style is optimized in order to anticipate possible stop&go situations and thus to dynamically adapt the cruise control. During congested periods, which typically occur during peak hours under bad weather conditions, an aggressive driving style can produce a significant divergence of the emissions, as evaluated during test session 2/1.

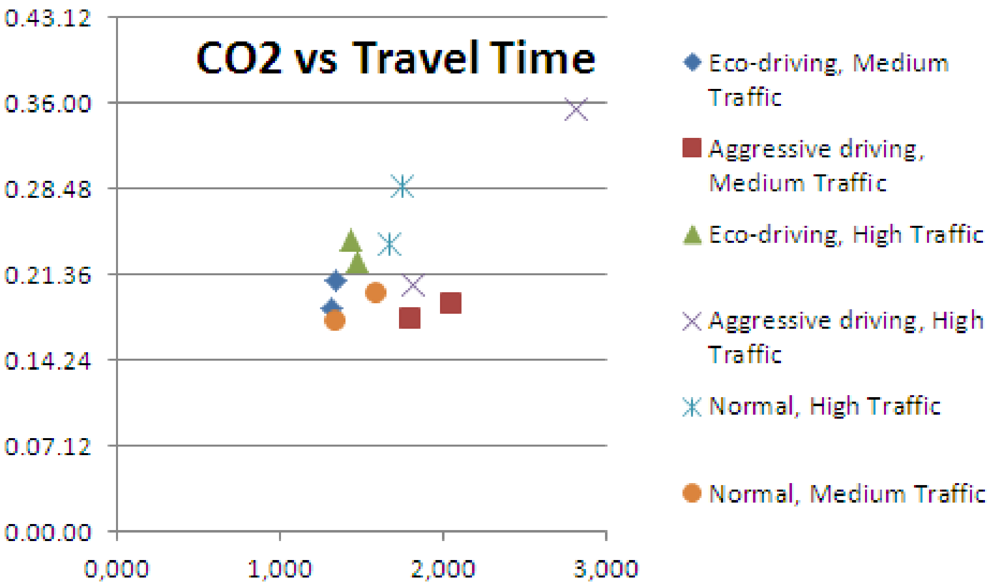


Figure 53: CO_2 emissions compared to travel times registered under different driving conditions.

Navigation factor. Four specific test sessions were organized under standard traffic conditions and by adopting a “normal” driving style in order to start to empirically evaluate the local impact of the navigation factor on the CO_2 emissions. Two test sessions (i.e. test sessions 7/1 and 7/2) followed navigation path n.1, and two test session (i.e. test sessions 8/1 and 8/2) followed navigation path n.2, already presented in Figure 49. The results of the measurement campaign are illustrated in Table 11.

Test session ID	Day	Start Time	Travel Time	Fuel consumption	CO_2 emissions	Number of Stop&Go
Test 7/1	16/05	15:21	00.13.20	0,434 [L]	1.033 [Kg]	6
Test 8/1	16/05	15:44	00.10.15	0,319 [L]	0,760 [Kg]	14
Test 7/2	21/05	15.14	00.14:00	0,463 [L]	1,102 [Kg]	8
Test 8/2	21/05	15:40	00.13.45	n.a.	n.a.	21

Table 11: The results of the baseline test sessions for the local assessment of the impact of navigation factor on CO_2 emissions.

These first results show that a choice of a particular path in the urban road network can have a significant impact on travel times and CO_2 emissions, and all this is a function of the current traffic conditions and of the road peculiarities of the paths under exam. In the case under evaluation, navigation path n.2 is significantly shorter than navigation path n.1, but can be periodically affected by higher traffic peaks. Test session 7/2 and 8/2 demonstrate that in certain occasions navigation path n.1 could be in general more “optimal” than navigation path n.2, with the possibility for drivers to take a longer path but giving a similar travel time and possibly producing a smaller amount of CO_2 emissions.

In conclusion, this preliminary measurement campaign allowed to empirically confirm that all evaluated microscopic factors have a certain impact on the amount of CO_2 emissions produced by vehicles moving in the urban area of Bolzano, and all these are source of inefficiency that can be properly addressed by the INTEGREEN project. This campaign also put in evidence the strong temporal variability of traffic conditions within the city, which suggests as possible efficiency measure to foster *temporal* navigation strategies (i.e. recommending travelers to start their travels at a specific time) instead of traditional *spatial* navigation strategies (i.e recommending travelers the best route in the current situation), which could be quite problematic and counter-productive for a rather small environment like the one of the city of Bolzano.

Finally, it is worth noting that these test sessions are not statistical sufficient for exhaustively describing the traffic and emission patterns in the area of interest. Therefore, more campaigns will be necessary during the project life time in order to better characterize the phenomenon under investigation, and evaluate its temporal change in the long-term period.

3 Stakeholders and users' needs

The objective of this chapter is to (i) identify reference stakeholders and users for the INTEGREEN system, and (ii) analyze the specific needs of each user category which is in relationship with the project target. These needs have to reveal the non-consistent expectations of users and stakeholders towards the system, including both explicit needs (i.e. needs which are clearly stated) and implicit needs (i.e. needs which are not clearly stated but are intrinsically latent).

3.1 Definitions

Before to enter in the details of this specific analysis, it is important to provide a detailed definition of "user" and "stakeholder" which applies for the INTEGREEN project:

- a "***user***" is an actor that is directly interacting with the INTEGREEN *system*, in particular through a specific interface and on the base of a specific application;
- a "***stakeholder***" is an actor that is not in direct contact with the INTEGREEN system, but is interested and/or involved in some aspects covered by the INTEGREN *project*.

3.2 Users and stakeholders identification

Local users and stakeholders of INTEGREEN are identified on the base of the definitions which are introduced in the paragraph before. This identification task avails of the support received by the activities performed in Action n.6, in which local users and stakeholders are addressed in order to raise their awareness about the local innovation introduced by the INTEGREEN project.

3.2.1 INTEGREEN users

The categories of users for INTEGREEN system are graphically illustrated in Figure 54, and can be summarized as follows:

- **Local travelers**. This category includes:
    - **Motorized vehicle drivers**, i.e. travelers that use a motorized vehicle to make an internal trip in the city of Bolzano or have the city as origin or destination in their trip plan. This category can be further characterized as follows:
        - **passenger car and light truck drivers**, i.e. drivers who travel in a light vehicle (i.e. car drivers and small truck drivers);
        - **passenger collective means and heavy trucks drivers**, i.e. drivers who travel in a heavy vehicle (i.e. bus drivers and heavy trucks drivers).

It is worth noting that car drivers can be further categorized as (i) **local citizens**, i.e.

users who belong to the local population and have a deep knowledge of the local road infrastructure and policies, and (ii) **seasonal travelers**, i.e. tourists and business men who travel through Bolzano only for a very limited period of time and have a low or medium knowledge of the urban road network.

Local travelers interact with the INTEGREEN system through the public web interface and on the base of pre-trip and on-trip applications.

- **Local transport planners**, i.e. operators which work in the freight and logistics sector. Similarly to local travelers, they interact with the INTEGREEN system through the public web interface and on the base of pre-trip and on-trip applications.
- **Road operators**, i.e. operators who are in charge of urban traffic management. This category includes:
  - **traffic officers**, who are responsible of the urban traffic control and to activate short-term intervention procedures in the case of necessity (e.g. accidents, queues, etc.). They interact with the INTEGREEN system through the operators web interface;
  - **traffic engineers**, who are responsible to analyze traffic in the mid-term and to identify, if necessary, specific traffic intervention policies to increase traffic fluency (e.g. traffic lights timing change). They interact with the INTEGREEN system through the traffic simulation and planning interface.
- **Mobile probes drivers**, i.e. drivers of fleet vehicles which are enabled in the future to bi-directionally communicate with the traffic management centre. This category should belong to the local travelers one, but has been specifically separated in order to identify the particular, future needs of this specific set of drivers.

3.2.2 INTEGREEN stakeholders

The categories of users for INTEGREEN system can be summarized as follows:

- **City Council of Bolzano**, which is responsible to define long-term and high-level traffic intervention policies (e.g. limited traffic zones definition, traffic limitations to pollutant vehicles, etc.).
- **Autonomous Province of Bolzano**, which is responsible to monitor air quality levels as well as traffic conditions on a regional scale.
- **Service providers**, who are in the conditions to build future telematic services that support the travelers to move in a more environmental-aware way, further reducing the emissions of their trips. As an example, possible services can allow a driver to identify a parking slot in the city, and possibly to remotely reserve it, or to book a goods delivery slot in the historical city centre.

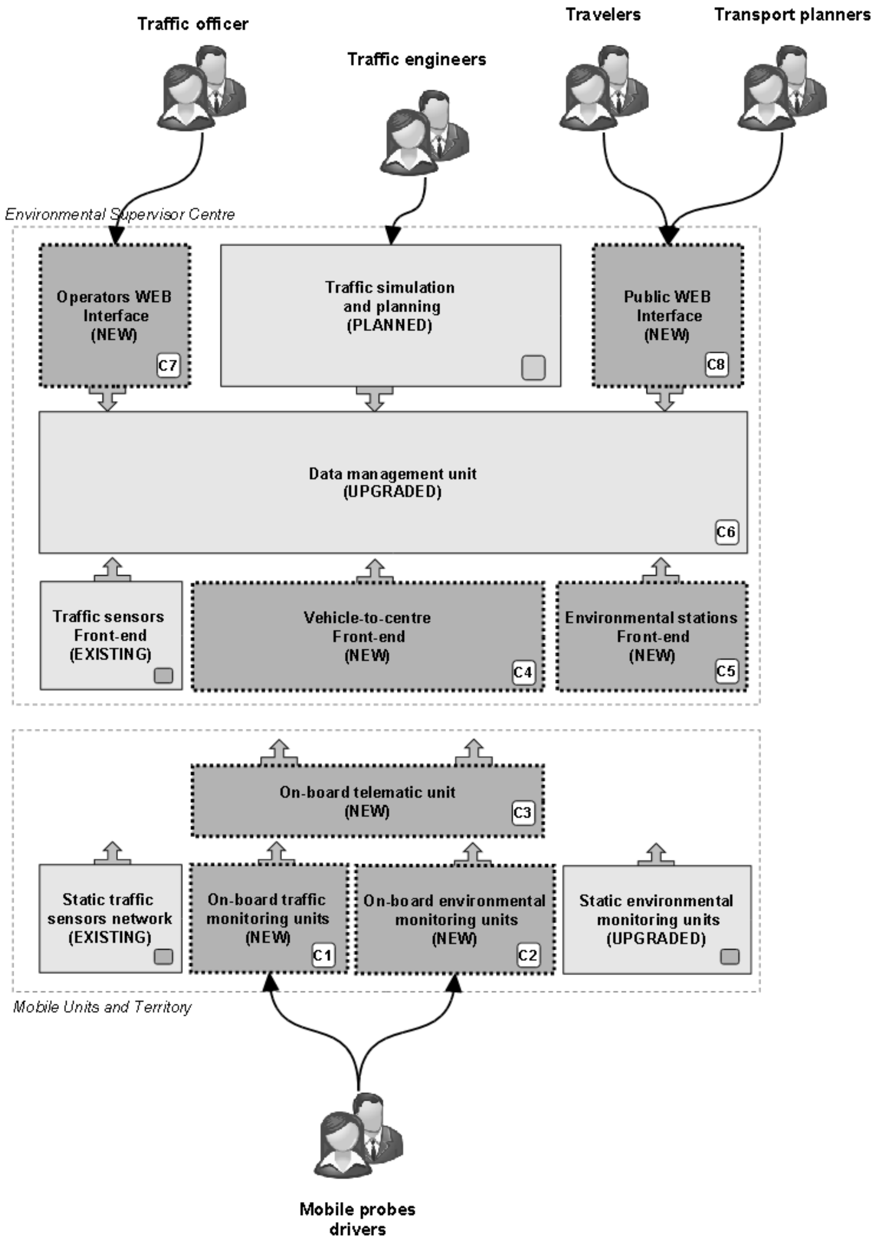


Figure 54: Interaction between users and INTEGREEN system.

- **Technology providers**, who are in the conditions to build future 3rd-party telematic applications that support the travelers to move in a more environmental-aware way, further reducing the emissions of their trips. As an example, navigation systems can integrate real-time traffic information collected by the Traffic Management Centre of Bolzano and indicate the route which minimizes the total emission consumption, while multimodal journey planners can use this information, together with public transport one, to provide travelers the best multi-modal travel combination for a specific trip at a given time, which maximizes the compromise between minimum travel time and minimum emissions generation.

- **Environment protection organizations, consumers' associations and driving schools/trainers**, who are in the conditions to educate travelers and to teach drivers to drive fuel-efficiently and safely.

- **Passenger fleet owners**, who are in the conditions not only to gain from the INTEGREEN system (drivers can reduce their fuel consumption), but also to exploit the mobile system architecture in their fleets.

3.3 Users and stakeholders needs

The user and stakeholder needs are per definition entirely user/stakeholder oriented and are not necessarily consistent. Local perspective is matched here with needs evidenced and proofed in state-of-art research projects, in particular eCoMove [21]- [22]- [23]- [24], which is an FP7- co-funded integrated project led by Ertico ITS Europe aiming at introducing systems and services based on cooperative mobility schemes with the specific target of maximizing energy efficiency and thus minimizing CO_2 emissions produced by road traffic[14]. The full set of needs is presented in Table 12.

[14] For more information about the eCoMove project, please refer to Chapter 6.

Users/stakeholder	Category	Membership class	Needs	
Local travelers (LT)	User	-	LT_1	The traveler shall be in the condition, depending on his/her particular mobility requirements, to choose the best urban travel option in both space and time dimension which optimizes the compromise between travel time and cost depending on real-time conditions.
			LT_2	The traveler should not be forced or limited in the travel decisions, but only have the minimum set of information that can efficiently support this decision-making process.
			LT_3	The INTEGREEN system should provide relevant recommendation according to the individual needs, both in the pre-trip and in the en-route phases, allowing dynamic modifications of the travel plan.
			LT_4	The system has to include additional information as well; for example, parking availability information can be a crucial information for deciding to take a car in the city. Air pollution levels can significantly influence trip decisions, in particular pollution hotspots can convince travelers to avoid travel choices which include these polluted areas.
			LT_5	Information received should be reliable and timely up-to-date, in order to maximize the efficiency of the travel decisions and thus the travelers' satisfaction.
			LT_6	The traveler desires that the air quality levels in the city are good, without any possible risk on his/her health.
			LT_7	The level of satisfaction of travelers is in general higher if the local public administration adopts proper soft and preventive traffic-related measures than hard and retroactive limitations for reducing the impact of traffic on the air

				quality. In this perspective, the city authorities should adopt policies based on incentives and benefits for intelligent and aware travelers, and penalize those who do not take care the system recommendations. In this way, it could be possible to foster a positive change in the travelling habits of the latter users.
			LT_8	The travelers accepts novel monitoring system which however demonstrate to guarantee their right to privacy.
Motorized vehicle drivers	User	Local travelers	MVD_1	The motorized vehicle drivers desires to avoid congestions or in general most crowded urban roads, in order to minimize the time of their travels.
			MVD_2	The INTEGREEN system should provide relevant recommendation for intelligent routing and for determining the best time of the day in which a trip should be made.
			MVD_3	The chosen route is selected on the base of different parameters: traffic level, travel time, route comfort level, air pollution level, safety.
			MVD_4	En-route information like timers at traffic lights could be beneficial for crossing relevant urban intersections in an efficient way.
			MVD_5	When a relevant traffic event appears (e.g. accident at a crucial intersection), the driver should be aware of it in a very short time.
Passenger car and light truck drivers	User	Motorized vehicle drivers	PC&LTD_1	Other relevant information that can significantly influence the choice of an urban trip is the amount of heavy vehicles (for example buses) present in a certain road section. Because of the limited road infrastructure, this has a significant impact not only on travel times (e.g. it is difficult to overtake a bus) but also on safety.
Passenger collective means and heavy trucks	User	Motorized	PCM&HTD_1	Every delay in the passengers or goods transport service has an operational cost in terms of fuel, salary, maintenance, and has an impact on clients'

drivers		vehicle drivers		satisfaction. Transport service efficiency should thus be maximized en-route through proper and timely-relevant urban travel recommendations, but without adding workload and causing distraction.
Local transport planners	User	-	LTP_1	LT_3 need is particular crucial for local transport planner, since a bad pre-trip decision can have significant negative consequences in terms of quality of service.
			LTP_2	Minimization of environmental footprint is becoming more and more a parameter of choice for the customer: for this reason, it is important to have means to demonstrate that the offered service is likely to minimize air pollutant emissions.
			LTP_3	In this sense, a key aspect which should be taken more and more in consideration is the optimization of drivers' style, which can have significant impacts on whole fuel consumption and thus on fuel costs and air pollutant emissions.
Road operators	User	-	RO_1	Urban traffic shall be managed in a way that the compromise between traffic throughput, quality of life and safety (in particular of vulnerable road users) is maximized over all road network. Limited road capacity has to be maximized in time and space, and road users should have a high quality travel service in the city.
			RO_2	The traffic management system should be able to adapt traffic strategies easily and dynamically.
			RO_3	Sensitive areas (for example residential districts) should be managed properly, in order to minimize the effect of traffic on the quality of life. In this perspective, air pollution levels are an important parameter to take under control.
			RO_4	The same categories of travelers should have in general the same treatment

				and levels of service; however, various policies should be applied depending on the type of vehicle and travel choices.
			RO_5	Connection with the city access gates is particularly important for a city like Bolzano; for this reason, it is fundamental to establish a strict cooperation between all local road operators.
			RO_6	Prevent traffic events is much more effective than reacting to them; for this reason, systems which can support preventing strategies are desirable.
Traffic officers	User	Road operators	TO_1	It is fundamental to have a clear and exhaustive up-to-date overview of traffic situation in the city.
			TO_2	The INTEGREEN system should allow to reduce the time which is needed to react to a traffic/environmental event, and possibly to enhance the ability to prevent such critical situations.
			TO_3	It should be possible to have instruments for timely recommending road users about best travel options and informing about traffic events. Ancillary information such as parking availability and air pollution hotspots should be provided to the travelers in a user-friendly way.
			TO_4	The INTEGREEN system should not increase the complexity and the amount of time which is necessary for the daily traffic management operations. The overall cost/benefit should be clear.
Traffic engineers	User	Road operators	TE_1	Monitoring systems should collect data than can be used for ex-post evaluations.
			TE_2	Novel traffic control solutions should be found in order to increase the capacity of existing bottlenecks in the urban road infrastructure, or at least to minimize

				the impact of a traffic event appearing in correspondence to these points.
			TE_3	Intelligent strategies have to be considered in order to reduce the transit of people and goods within the residential districts of the city; in particular, proper countermeasures targeting heavy goods vehicles have to be addressed in order to increase safety and comfort in these areas, reduce pollutant emissions and thus increase the overall quality of life.
			TE_4	It is fundamental to prioritize sustainable mobility in the city, in particular bicycles, public transport and pedestrians, for example through dedicated lanes. Safety issues have to be properly taken into account during the design process of an urban intervention on the road.
Mobile probes drivers	User	-	MPD_1	The collection of mobile data from the traffic management centre should be as transparent as possible, and not further complicate the driving operations, neither contribute to increase driver's distraction.
			MPD_2	The en-route information received by the traffic management centre should be reliable, consistent and significantly impacting the original trip choice (if applies, e.g. car sharing) or the normal level service (e.g. public transport).
City Council of Bolzano	Stakeholder	-	CCB_1	Urban road traffic management should be able to minimize the number of accidents.
			CCB_2	Urban road traffic management should be able to minimize the overall fuel consumption and emissions.
			CCB_3	The right to mobility has to be guaranteed to every category of local travelers, with particular attention to those with reduced mobility ability (e.g. elderly people, people with motor impairments, etc.).
			CCB_4	The quality and safety of citizens' life takes precedence in the residential areas

				over traffic flows efficiency; traffic management policies have to consider this factor in the definition of access rules for different type of vehicles. The general objective is to maximize satisfaction among local citizens about traffic conditions in the city.
			CCB_5	Sustainable and efficient transport means, alternative to individual car, have to be favored for short trips within the city. Avoidable and parasitic car travels (for example, looking for an empty parking slot) should be minimized as possible.
			CCB_6	Accessibility to the city should be guaranteed independently from users' demand and weather conditions; however, critical events should be prevented as much as possible, and arrivals/departures should be organized wisely, in order to maximize the positive image of the city and the economical return produced by tourism.
			CCB_7	The maximum compromise between efficiency in traffic management operations and related costs should be obtained; a clear cost/benefit assessment produced in particular by INTEGREEN system should be demonstrated.
Autonomous Province of Bolzano	Stakeholder	-	APB_1	It is necessary a strict and continuous cooperation between municipal and regional traffic management centres, in order to optimize and maximize the available monitoring capabilities and the integration of traffic regulations and countermeasures.
			APB_2	Multi-modal approaches based on integrated public transport services should be stimulated as much as possible through proper incentives as well as reliable and up-to-date information that allow users to efficiently organize their local travels.
Service and technology providers	Stakeholder	-	S&TP_1	Traffic and mobility-related information collected by the traffic management centre should be reliable and timely-relevant. This information shall be usable by third parties in order to offer new telematic services and applications for the

				local travelers.
Environment protection organizations	Stakeholder	-	EPO_1	Environment protection, in particular in terms of air quality, has to be more and more a must in the area of interest of the project for local policy makers. Emissions caused by traffic should be reduced as much as possible through targeted and integrated sustainable traffic and mobility management strategies. Modal split towards sustainable transport means and intelligent approaches for a more efficient use of existing urban road infrastructure should be introduced.
			EPO_2	Drivers themselves can have a significant role in the overall emissions caused by traffic: an increased awareness and responsibility assignment of their carbon footprint is therefore necessary, For creating a similar environment, is however recommended to introduce an incentive system aiming at rewarding travelers who decide to adopt sustainable travel options.
Consumers' associations	Stakeholder	-	CA_1	The right of mobility shall not be in any case limited or denied.
			CA_2	It is important to educate people, and to provide them the right information and instruments to plan urban trips in an aware way. The diffusion of false convictions and thus of bad and inefficient behaviors shall be avoided as much as possible. People have to be able to find reliable information sources (e.g. on the web) with practical and few tips for eco-travelling and driving.
Driving schools/trainers	Stakeholder	-	DS_1	Eco-driving recommendations shall be introduced more and more in the driving education courses programs, but without significantly impacting other important aspects of road safety education. Theoretical lessons as well as practical eco-driving guides should be considered. Eco-driving should become one of the main pillars of driving education.
Passenger fleet owners	Stakeholder	-	PFO_1	The INTEGREEN mobile system should be of easy integration in the fleet monitoring system and not put into question the performance of the existing

[redacted]				Automatic Vehicle Monitoring (AVM) applications.
			PFO_2	The data collection functionalities as well as the novel info-mobility services should be as transparent as possible, and not increase the activities of the drivers neither negatively impact their distraction.
			PFO_3	The overall cost/benefit of the system should be evidenced.

Table 12: Users and stakeholders needs description.

4 Targeted inefficiencies

This chapter aims to present the results of the preliminary studies concerning the common inefficiencies that appear during a vehicular trip in the urban area of interest (i.e. the city of Bolzano), both in the pre-trip and en-route phases. Inefficiencies highlighted in several research studies available in the international state-of-art and which have a non-negligible impact on emissions have been evaluated and weighted as a function of the main local peculiarities and issues that have already been discussed in the previous chapters, and which are summarized in Table 13.

Nr.	Nature	Statement
1	Traffic	Amount of heavy vehicles circulating in the urban area of Bolzano
2	Traffic	Presence of seasonal traffic peaks
3	Traffic	Transit traffic in the residential areas
4	Traffic	A22 highway crossing the city
5	Air pollution	Considerable amount of CO_2 emissions produced by road traffic
6	Air pollution	Considerable amount of NO_x (and PM_{10}) emissions produced by road traffic

Table 13: Local traffic and air pollution main peculiarities and issues.

Structural interventions in terms of creation of road (and rail) infrastructures are foreseen by the Urban Mobility Plan in the long term; an advanced management of urban traffic which considers environmental issues as well is going to be introduced in INTEGREEN in a shorter time horizon, with the potential to provide a relevant contribution in addressing the present challenges. Furthermore, INTEGREEN is going to evaluate the environmental effect produced by queues and traffic jams, and allow a more detailed understanding of the impact on air pollution produced by different traffic situations in the city.

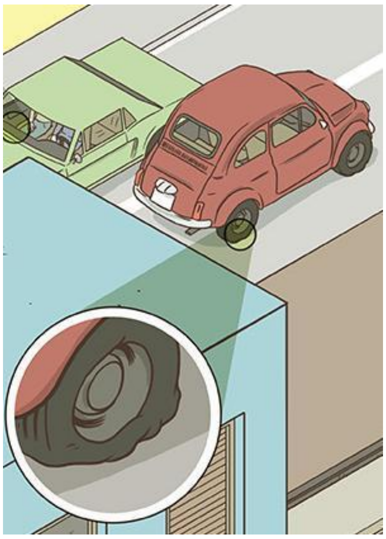
4.1 Pre-trip inefficiencies

The list of pre-trip inefficiencies are presented in Table 14.

ID	Inefficiency	Reference parameters	Level of relevance
INEF _01	**Inefficient vehicle condition**	Tire pressure Tire condition Maintenance status	Small

		Vehicle loading Equipment influencing aerodynamics	
INEF _02	**Inefficient route choice**	Lack of knowledge on traffic state on selected route Insufficient knowledge about route alternatives Insufficient knowledge about factors influencing consumption on the route	Medium
INEF _03	**Inefficient travel timing**	Congestion during peak hours Traffic jam caused by accident Weather conditions	High
INEF _04	**Inefficient payload**	Number of empty travels of trucks	Medium
INEF _05	**Inefficient modal choice**	Lack of knowledge about estimated real-time travel times with different transport modes Lack of multimodal urban journey planner	Medium

Table 14: Pre-trip inefficiencies and environmental impact in the city of Bolzano.



Inefficient vehicle condition. Tire pressure, tire condition and maintenance status are parameters which can be measured by the on-board systems, while the other factors are out of control for them.

Typical values of tire pressures are 200 – 240 [kPa], and several studies available in the state-of-art have shown that on average the fuel consumption increases of 1% for every 20 [kPa], which is the typical pressure loss in a time period of a month [25]. Tire pressure is proportional to air temperature as well: a drop of 10 [°C] determines a reduction of about 10 [kPa].

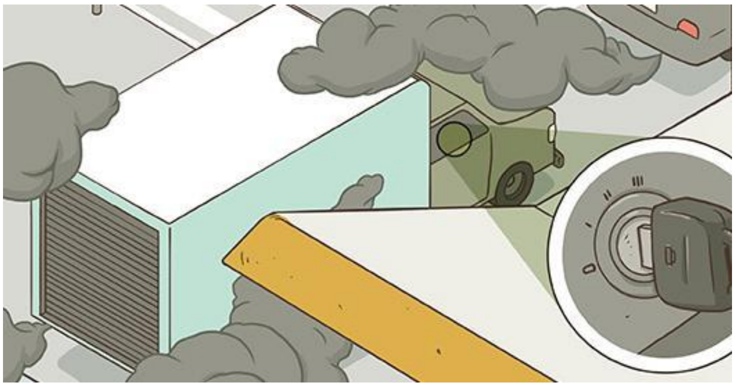
The effect of vehicle loading is quite limited: it is estimated that an increase in weight of 20 [Kg] causes an increase of fuel consumption of 0.5%. On the other side, the introduction of equipment influencing aerodynamics such as roof pack can produce an increase of fuel consumption of 10%

[26]. Despite the relevant flows of tourists characterizing the urban area of Bolzano, this aspect can be considered “small” in terms of environmental impacts.

Inefficient route choice. This inefficiency can be considered of “medium” relevance since (i) local travelers have very little information about traffic status in the city of Bolzano and in the surrounding area, and (ii) a non-negligible component of traffic is caused by people not living in the city (i.e. tourists or inhabitants of the region coming from the valleys) which are not fully aware of the available route alternative and related fuel consumption amount (a shorter route could not be the optimum choice in environmental terms).

Inefficient travel time. The same considerations can apply for this type of inefficiency, which is related to a suboptimum choice in the definition of the start time; however, since the urban road infrastructure is limited in capacity, congestion phenomena during peaks hours or worse traffic jams caused by accidents or weather events are likely to produce severe effects on the air quality in the city. In particular, weather events have the effect to produce a local variation in the urban modal split: in particular, many bicycle users decide to take their own car in these situation contributing in an increase of the overall traffic volumes.

Inefficient payload. This inefficiency refers to one of the main problems of the city of Bolzano, which is the amount of trucks travelling within the city, not only in the industrial area but even in the residential districts and in the city centre. Several studies available in the state-of-art show that there is still a considerable amount of heavy vehicles which travel empty: despite efforts to improve freight transport efficiency, a cargo truck driving on European roads currently still spends around half of its working life empty - returning from a delivery or travelling to pick up its next shipment [27]. This issue can however not be specifically addressed within INTEGREEN project since it necessary to significantly modify the travel patterns of these vehicles through for example the creation of a logistic centre that can manage centrally the last mile delivery of goods in the city.



Inefficient modal choice. This inefficiency takes in consideration the contribution produced by car travelers who could be in the condition, based on his/her specific constraints, to adopt a more environmental friendly transport option for their urban trips. Even if the modal split in Bolzano is already excellent, there is still a relevant amount of local travelers who decide to take the car instead of other means such as bicycle or public transport, even if these solutions could be, in certain occasions, quicker than the private car.

Table 15 summarizes the position of INTEGREEN with respect with all these inefficiencies and, where applicable, illustrates the type of intervention which will be carried out in order to address them.

ID	Inefficiency	Action / type of intervention
INEF_01	**Inefficient vehicle condition**	**Targeted by the INTEGREEN project** (i.e. awareness-raising campaign, educational activities, etc.)
INEF_02	**Inefficient route choice**	Targeted by INTEGREEN system
INEF_03	**Inefficient travel timing**	Targeted by INTEGREEN system
INEF_04	**Inefficient payload**	Outside the scope of INTEGREEN
INEF_05	**Inefficient modal choice**	Targeted by INTEGREEN system

Table 15: Pre-trip inefficiencies and type of intervention proposed by INTEGREEN.

4.2 En-route inefficiencies

The list of en-route inefficiencies are presented in Table 16.

En-route inefficiencies can be categorized in the different inefficiency classes:

- inefficiencies in vehicle condition and energy consumers on board;
- inefficiencies in **secondary driving tasks**, i.e. tasks which are related to the aspects of finding the way to destination in the traffic and in the road network;
- Inefficiencies in **primary driving tasks**, i.e. tasks which refer to the operation of the vehicle and that can be induced by different contextual situations.

ID	Inefficiency	Reference parameters	Level of relevance
INEF_06	**Inefficient use of electrical energy consumers and vehicle conditions**	Electrical auxiliary on-board systems Open windows Tire pressure	Medium
INEF_07	**Inefficient routing**	Traffic situation Traffic lights	High

		External influences Parking availability	
INEF_08	**Inefficient driving**	Acceleration/deceleration Idling Speed Gear/RPM	High

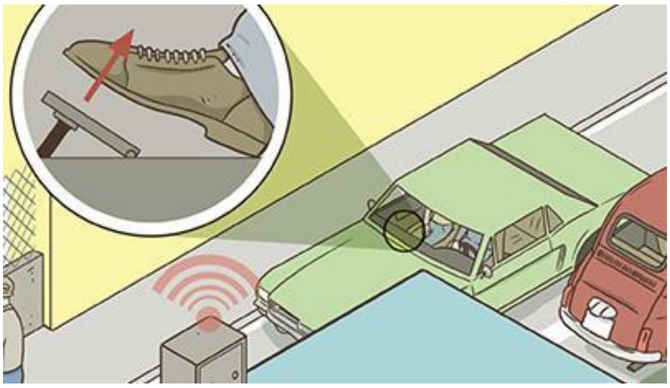
Table 16: En-route inefficiencies and environmental impact in the city of Bolzano.

Inefficient use of electrical energy consumers and vehicle conditions. Air conditioning is the on-board electronic system which has the highest impact in terms of fuel consumption and emissions. A recent study undertaken by Empa, a Swiss research centre, on behalf of the Swiss Federal Office for the Environment (FOEN) has revealed that the typical increase in fuel consumption is in the order of 10% in correspondence of urban trips, which are the most critical ones since the average travel speed is much lower than in other scenarios like suburban roads and highways [28]. These values can increase up to 18% during typical summer Swiss days, which at a first glance can be directly comparable with the typical weather conditions of South Tyrol. An interesting information is related to the existing level of inefficiency: it is estimated that about the 65% of this additional fuel consumption could be saved if air conditioning systems are turned off when external air temperature is below 18 [°C]. From an environmental point of view, it is in general recommended to limit the use of air conditioning systems in urban areas, and instead open the windows, especially during idling times.

Inefficient routing. This inefficiency is strongly related to INEF_02 and INEF_03. Traffic conditions are high variant, and can change significantly during the passage from pre-trip organization and en-route trip. In order to minimize the fuel consumption and thus the impact on the environment, drivers should know, possible in an integrated way:

- the real-time traffic situation of the different possible routes; at least if a traffic event appears, a driver should be informed promptly in order to avoid it;
- the current timing of traffic lights, in order to minimize the idling times caused by red lights;
- the presence of heavy vehicles, in particular large trucks and buses, which can significantly influence the trip on a specific route; this is in particular a very complex issue to be solved in Bolzano since the urban road infrastructure at disposal is quite limited, even if the number of dedicated bus lanes is continuously increasing;
- the availability of parking slots at destination, which is an information that drivers currently have through the parking guide information systems.

Despite this latter point, it is evident that a significant optimization can be introduced here if timely validated information can be provided to the drivers.



Inefficient driving. Even if the selected route is the optimum one, the amount of fuel consumption and thus of air pollutant emissions can be however high if the driver uses an inefficient driving style. The on-board behavior is of course influenced by many factors, such as traffic levels, road type, weather and environment conditions, traffic signals, vehicle conditions, driver attitude. Even if the relevancy of this inefficiency is high, this will be only in part targeted by the INTEGREEN *system*; indeed, a most efficient management and control of urban traffic and air pollution levels can however lead to better contextual driving conditions and thus to an indirect but significant improvement in terms of driving efficiency.

Table 16 finally illustrates how INTEGREEN is going to target the identified en-route inefficiencies.

ID	Inefficiency	Action / type of intervention
INEF_06	**Inefficient use of electrical energy consumers**	**Targeted by the INTEGREEN project** (i.e. awareness-raising campaign, educational activities, etc.)
INEF_07	**Inefficient routing**	Targeted by INTEGREEN system
INEF_08	**Inefficient driving**	Targeted by INTEGREEN system, Awareness-raising campaign, educational activities

Table 17: En-route inefficiencies and type of intervention proposed by INTEGREEN.

5 Use case analysis

The goal of this chapter is to understand how identified inefficiencies can be targeted through the INTEGREEN system. The approach which is used for this analysis is to identify reference use cases, which analyze through likely situations how pre-trip and en-route inefficiencies could be efficiently addressed. The complete set of use cases is listed in Table 18.

ID	Use case	Trip phase	Reference User
UC_1	**Local travelers getting information for an eco-trip**	Pre-trip	Local travelers
UC_2	**Local fleet managers getting information for an eco-trip**	Pre-trip	Local transport planners
UC_3	**En-route driver information through VMS**	En-route	Local travelers
UC_4	**En-route driver information on-board demonstrator**	En-route	Mobile probes drivers
UC_5	**Traffic and environmental status assessment: INTEGRATED MONITORING**	Pre-trip / En-route	Traffic officers / engineers
UC_6	**Traffic controllers adaptive coordination: ACTUATION**	Pre-trip / En-route	Traffic officers / engineers

Table 18: Full set of INTEGREEN use cases.

5.1 Definitions

In order to guarantee that use cases are understood well without any kind of multiple interpretations, the following definitions are introduced.

- **Monitoring actors**. Monitoring actors are all system elements that gather data about current traffic and/or air pollution conditions and send it to the Supervisor Centre. They can be categorized as:
  - ✓ **fixed stations**, i.e. monitoring actors which acquire data from a specific point of the road network;
  - ✓ **mobile probes**, i.e. monitoring actors which are in the conditions, during the same data acquisition process, to acquire data from several points of the road network;
  - ✓ **traffic officers**, i.e. personnel at the Supervisor Centre who is charge to insert data about programmed events in the road-network (e.g. road works).

The mobile-probes are furthermore in the conditions to notify the Supervisor Centre about the presence of particular traffic events (e.g., incidents, traffic-jam) or quite alarming situations concerning the safety of drivers and roads (e.g., a broken traffic-light, damages caused by third parties etc.). Once detected, the Supervisor Centre is alerted by means of the notifications sent by mobile-probe drivers.

- **Raw data**. Raw data are streams of low-level information sent periodically at fixed time frames by all monitoring actors to the Supervisor Centre. Once received this data, the task of the Supervisor Centre is to detect specific events happening on the roads by means of complex algorithms and models which avails of historical data as well in order to improve the reliability of the generated output results.;

- **Events.** Events are high-level *notifications* which can be sent to the Supervisor Centre only by a specific set of monitoring actors. According to their nature, events can be classified as:

  - ✓ **unpredictable events**, for which it is not possible or is quite hard to forecast the exact time frame in which they will occur (e.g., an accident, a pollution peak, a traffic-jam etc.). As a result, these events are typically notified to the Supervisor Centre meanwhile they occur, and require *reactive* countermeasures;

  - ✓ **short-term predictable events**, for which it is possible to forecast in advance their occurrence but only in the short-term period on the base of an analysis of the current conditions of traffic, air pollution and weather. Given these premises, the Supervisor Centre has the ability to activate *proactive* strategies.

  - ✓ **programmed events**, i.e. all those events such as road works and city events (periodic or extraordinary) whose lifetime is well-known in advance. These events are notified to the Supervisor Centre by the traffic-officers only.

5.2 Use case descriptions

A detailed evaluation of each use case can be found in the following tables.

Name	Local travelers getting information for an eco-trip
Use case ID	UC_1
Version	V01
Author(s)	Paolo Valleri, Roberto Cavaliere (TIS)
Contributing partners	AIT, CBZ
Short	Eco-travelers can optimize their urban travels plan choices based on the current traffic and air quality conditions. Thanks to a precise knowledge of the real-time

Description	situation (e.g., traffic and air pollution patterns, road events, etc.) they are in the conditions to: • avoid to pass through congested and/or polluted areas; • schedule their car trips to avoid the peak hours; • choose the most appropriate travel mean(s); • schedule their movements in order to perform more errands along the same trip. By doing so, they will be in the condition to: • limit their private car use; • increase the efficiency in the way they use the available road infrastructure resources (roads, parking areas, etc.), in time and space; • reduce the environmental impact of their travels.
Goal	The overall goal is to minimize the ecological footprint of an urban travel by: • choosing the most eco-compatible route as a function of the current traffic / air quality situation; • scheduling the trip in order to avoid traffic peaks; • performing more errands along the same trip; • choosing the most appropriate travel mean(s) according to the specific travel constraints.
Actors	• All travelers (including drivers) moving in the urban area of Bolzano; • info-mobility channels (online services); • traffic officers.
Constraints (use case)	Historical and real-time information about air quality and traffic situations in the different areas of the city must be available and accessible from an online service (i.e., website, mobile app, etc.).
Constraints (actor)	Actors can have several limitation in both the time and space domain, i.e.: • scheduling the trip in different hours could be hard for specific errands; • travel time choice cannot be always possible; • destination could be in areas with high-traffic density; • route alternatives can be difficult to identify; • the urban road infrastructure does not offer a plenty of routing choices; • the travelers can have only a very limited knowledge of the urban road infrastructure.
Driving situation	Pre-trip situation (Before starting the trip)
Vehicle type & state	Personal vehicles.
Inefficiency addressed	• Inefficient route choice (INEF_02) • Inefficient travel timing (INEF_03) • Inefficient modal choice (INEF_05)

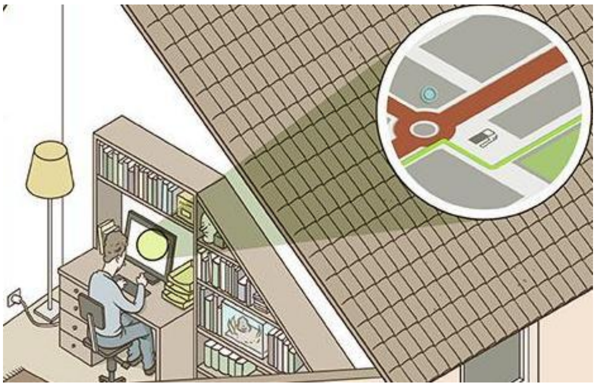
Pre-condition	The traveler wants to plan his/her trip and errands according not only to his/her specific cost and time constraints but also with the awareness of reducing the ecological footprint of his/her travel choices.
Post-condition	The traveler considers the information provided by the online service.
Main flow	A traveler has a specific travel demand, which can be characterized (or not) by a certain temporal deadline. He/she has to move from A to B in the city, and can have (or not) a certain amount of time to plan and carry out his/her trip. The traveler evaluates if he/she can aggregate more than one errand with the same trip. The traveler checks the online service in order to understand: • the most appropriate route choice; • the most appropriate travel time choice (if applicable); • the most appropriate travel mean(s).
Exceptions	In certain situations, travelers can have specific personal needs which are in contrast with the optimal travel choice in global terms. Namely, the travel choice can have a relevant degree of sub-optimality with respect to the most efficient one.
Reference scenario(s)	• **SC1: travelers optimizing route plan based on traffic jams and/or pollution peaks** • **SC2: travelers optimizing travel plans in the time domain** • **SC3: travelers optimizing travel plan by means of efficient multi-modal choices**  
Dependency with other UCs	• Traffic and environmental status assessment: INTEGRATED MONITORING (UC_5)

Table 19: Use case 1 description details.

Name	Local fleet managers getting information for an eco-trip
Use case ID	UC_2
Version	V01

<table>
<tr><td>Author(s)</td><td>Paolo Valleri, Roberto Cavaliere (TIS)</td></tr>
<tr><td>Contributing partners</td><td>AIT, CBZ</td></tr>
<tr><td>Short Description</td><td>Local fleet management companies are in the conditions to optimize the errands and the trips of their fleet vehicles based on:
• real-time traffic and air pollution information;
• typical daily traffic – air pollution levels patterns;
• presence of road events;
In this way, local fleet management companies are in the condition to:
• increase the efficiency in the way they use the available road infrastructure resources (roads, parking areas, etc.), in time and space;
• reduce the environmental impact of their travels;
• reduce their transport costs;</td></tr>
<tr><td>Goal</td><td>The main goals are:
• to minimize the ecological footprint of local fleet vehicles trips in the urban area of Bolzano through a provision of detailed traffic and air pollution levels information;
• to allow local freight transports to improve the efficiency of their last mile transport services in the city.</td></tr>
<tr><td>Actors</td><td>• local fleet managers;
• info-mobility channels (online services);
• traffic officers.</td></tr>
<tr><td>Constraints</td><td>• transport service and resources constraints (available vehicles, available drivers, delivery constraints);
• real-time traffic Information must be available and accessible by local fleet managers;
• real-time air pollution information must be available and accessible by local fleet managers;
• typical pattern information must be available and accessible by local fleet managers.</td></tr>
<tr><td>Driving situation</td><td>Pre-trip situation (Before starting the trip)</td></tr>
<tr><td>Vehicle type & state</td><td>Light commercial vehicles, heavy trucks, local public transport fleets.</td></tr>
<tr><td>Inefficiency addressed</td><td>• Inefficient route choice (INEF_02)
• Inefficient travel timing (INEF_03)</td></tr>
<tr><td>Pre-condition</td><td>The fleet managers want to minimize the transport costs and maximize the efficiency of the delivery service.</td></tr>
<tr><td>Post-condition</td><td>The fleet vehicle driver follows the planned eco-trip recommendations.</td></tr>
</table>

Main flow	According to both traffic and air pollution information provided by an online service, and the available resources and service deadlines, a local fleet manager is able to optimize the trips and errands of his/her fleet of vehicles, thus determining a minor impact on the environment, an improved quality of their transport services and a reduction in their travel costs.
Exceptions	In certain situations, fleet managers can have specific constraints (limited available resources in terms of vehicles and drivers, delivery deadlines, etc.) which do not allow them to select the optimal trip choice in global terms. In other words, the trip choice can have a relevant degree of sub-optimality with respect to the most efficient one.
Reference scenario(s)	• **SC1: local freight transport services managers optimizing travel plan based on traffic jams and/or pollution peaks** • **SC2: local public transport services managers optimizing transport services based on typical traffic and air pollution patterns** 
Dependency with other UCs	• Traffic and environmental status assessment: INTEGRATED MONITORING (UC_5)

Table 20: Use case 2 description details.

Name	En-route driver information through VMS
Use case ID	UC_3
Version	V01
Author(s)	Paolo Valleri, Roberto Cavaliere (TIS)
Contributing partners	AIT, CBZ
Short Description	Variable Message Signs (VMSs) are electronic traffic signs used by road authorities to provide travelers with dynamic information. This can be in form of (i) real-time information (textual and or numerical data), typically in form of well-defined advise for particular situations (e.g. indications to reach the city centre, presence of accidents and/or congestion phenomena, road construction sites,

	number of available parking slots in the parking areas, etc.), and (ii) real-time local data (numerical data only), referred for example to the current timing of the traffic signal cycle (i.e., a counter showing the number of missing seconds before the transition to another phase) or the correct speed to use in order to reach the next intersection when the traffic light is green. Drivers will be in the condition to optimize their travels (eventually adapting their travel plan) thanks to the information provided by the VMSs. In the case of (i), they will have the possibility to be informed about the road network aspects of the city, and to have at disposal practical indications in order to best reach, in the current situation, the main destinations inside the city (even considering multi-modal alternatives). This information will be directly and actively provided and supervised by the traffic officers of the Supervisor Centre, based on the current status provided by the integrated monitoring system, and eventually on the contingent action plan that they may have adopted. In the case of (ii), drivers will be in the condition to optimize their crossing at traffic light intersections, with the possibility to produce a direct and positive impact on traffic fluidity, travel times and above all air pollution generated by stop&go situations. According to the timer displayed on the VMS, drivers can adapt their vehicle speeds to reach the intersection when the traffic light is green.
Goal	The main goal is to minimize the environmental impact of drivers moving inside the city of Bolzano through the VMS infrastructure by (i) providing useful en-route information and (ii) positively influencing driving styles.
Actors	• all drivers moving inside the city of Bolzano; • VMSs; • traffic officers.
Constraints	The Supervisor Centre has the technical capability to (i) have access, (ii) manage and (iii) spread all the information related to the traffic and air pollution events.
Driving situation	En-route situation (during the trip)
Vehicle type & state	All types of vehicles.
Inefficiency addressed	• Inefficient routing (INEF_07) • Inefficient driving (INEF_08)
Pre-condition	• VMSs must be installed at specific traffic light intersections; • VMSs information must be coordinated by the traffic officers of the Supervisor Centre; • drivers respect the traffic laws in correspondence of the traffic light intersections.
Post-condition	Drivers take in active consideration the information displayed on the VMSs.
Main flow	In the case of (i) (real-time information VMSs), drivers are influenced by the displayed messages, which are fully controlled and supervised by the traffic officers of the Supervisor Centre. They can thus decide to adapt their route/travel

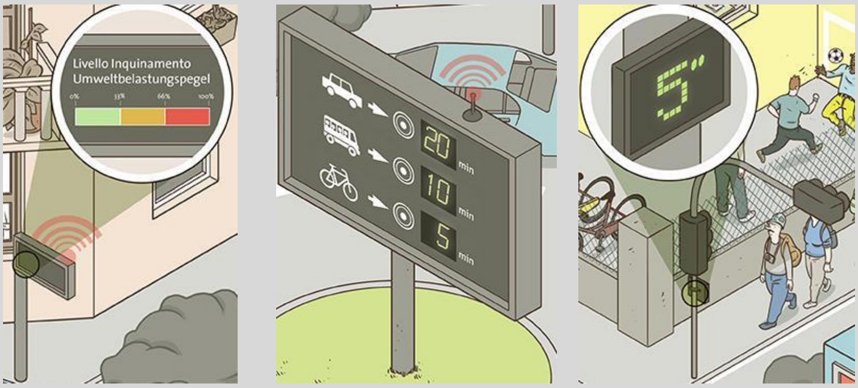
	plan according to the current traffic and air pollution conditions. In the case of (ii) (real-time local data VMSs), drivers can visualize the current timing related to a traffic light, and harmonize their driving behavior in order to cross the intersection in shorter time and minimize their number of stop&go (and thus their impact on local air pollution).
Exceptions	Specific individual needs can be conflicting with respect to the messages available on the VMSs.
Reference scenario(s)	• **SC1: drivers change planned route based on a sudden air pollution peak displayed on a VMS** • **SC2: drivers change planned trip (i.e. change transport mode) based on a sudden traffic jam displayed on a VMS** • **SC3: drivers optimize their speed when intersecting a traffic light in order to take the green phase** 
Dependency with other UCs	• Traffic and environmental status assessment: INTEGRATED MONITORING (UC_5) • Traffic controllers adaptive coordination: ACTUATION (UC_6)

Table 21: Use case 3 description details.

Name	En-route driver information on-board demonstrator
Use case ID	UC_4
Version	V01
Author(s)	Paolo Valleri, Roberto Cavaliere (TIS)
Contributing partners	AIT, CBZ
Short Description	Mobile probes are those particular vehicles which are properly equipped with sensor devices in order to support the task of traffic and air pollution monitoring. The probes have a direct bi-directional channel with the Supervisor Centre which

	allow them not only to deliver the pre-processed gathered data but also to receive specific info-mobility information (including notifications of events) which can help the mobile probes drivers to move more efficiently in the city.
Goal	The main goal is to provide the mobile probes drivers with selected real-time traffic and air pollution information in order to (i) further increase, where applicable, the car travel efficiency in the city, and (ii) eventually distribute, for example in case of public transportation means, up-to-date information to the passengers on board.
Actors	• mobile probes drivers; • traffic officers.
Constraints	• The data gathered by the mobile probes must be sent and handled in time by the Supervisor Centre. Namely the Supervisor Centre might have the time to analyze the gathered data in order to detect the events happing in the monitored area. • The notifications have to be made independently according to the specific position of the mobile probes.
Driving situation	En-route situation (during the trip)
Vehicle type & state	Mobile probes
Inefficiency addressed	• Inefficient routing (INEF_07)
Pre-condition	A bi-directional channel shall be established between the mobile probe and the Supervisor Centre.
Post-condition	Mobile probes drivers take in active consideration the information available on board.
Main flow	• According to the position of the mobile probes, the Supervisor Centre identifies which notifications are of potential interest of which mobile probes (e.g. according for example to a distance or travel time estimation criterions). • The Supervisor Centre notifies the selected mobile probes about the events detected. • The driver can take advantage of the notifications received, and where applicable, he/she can modify the chosen route and/or improves the quality of the passengers transport service.
Exceptions	The notifications sent by the Supervisor Centre cannot always be taken in consideration by mobile probes drivers. For example, in the case the probe is a bus, the driver cannot change the route of the bus line (which is typically fixed), but can at least distribute this information with the passengers on-board (e.g. through an on-board VMS) and adapt accordingly his/her driving behavior (for example, in case of accident, he/she can avoid possible danger situations; in case of air pollution peak, he/she can try to minimize, where possible the pollutant emissions).

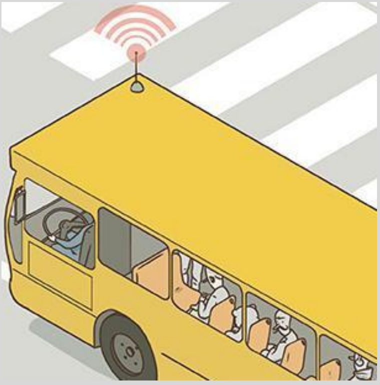
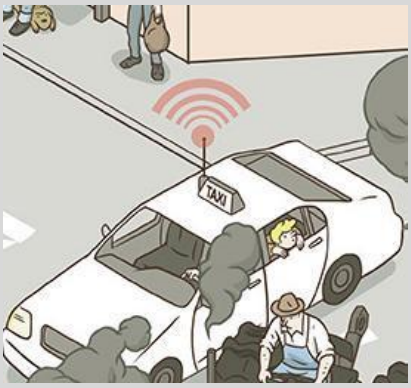
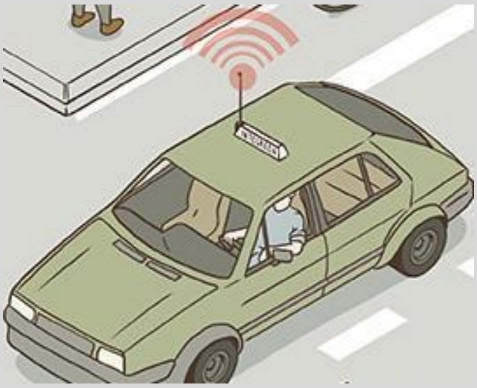
Reference scenario(s)	• **SC1: bus drivers optimize transport service en-route based on the individual information received by the Supervisor Centre** • **SC2: taxi drivers optimize transport service en-route based on the individual information received by the Supervisor Centre** • **SC3: car sharing drivers optimize their route plans based on the individual information received by the Supervisor Centre**   
Dependency with other UCs	• Traffic and environmental status assessment: INTEGRATED MONITORING (UC_5)

Table 22: Use case 4 description details.

Name	Traffic and environmental status assessment: INTEGRATED MONITORING
Use case ID	UC_5
Version	V01
Author(s)	Paolo Valleri, Roberto Cavaliere (TIS)
Contributing partners	AIT, CBZ
Short	The **integrated monitoring system** is located at the Supervisor Centre and it is composed of three different units. An integrated monitoring unit, implemented

Description	through static and mobile probes (monitoring actors), allows the Supervisor Centre to get, on a real-time basis, a very precise picture of the current traffic and air pollution situation of the monitored area. The information sent by the monitoring actors are raw data, streams of low-level information sent by all the components belonging to the monitoring infrastructure. The data gathered are received by the Supervisor Centre periodically from the monitoring actors. Once received, the task of the second unit at the Supervisor Centre is to **detect significant events** happening in the roads by running specific elaborations based on the data received. As a result of these activities, the Supervisor Centre is able to firstly estimate the presence of events in the monitored area and secondly to spread through the info-mobility channels the output generated. The **info-mobility channels** are the third unit of the monitoring system at the supervisor centre and has the role of spreading information about specific events. These info-mobility channels (web-based/mobile applications/VMSs) provide relevant information for the local travelers, which might support them before and during an urban trip.
Goal	The main goals are to: • improve the spatial detail and the time to reaction provided by the today's traffic monitoring system; • integrate the real-time traffic monitoring system with a real-time air pollution monitoring system, in order to create the premises for an integrated monitoring approach based on the “environmental traffic management” concept; • implement a central elaboration point where the data gathered by the monitoring actors are collected and elaborated in order to feed the info-mobility channels with high-level information about the conditions of the road-network; • allow a direct and automatic synchronization between the outputs of the integrated monitoring subsystem and the on-line info-mobility channels; • allow the traffic officers to insert manual notifications/messages/information in the available info-mobility channels.
Actors	• monitoring actors; • Supervisor Centre components (acquisition and elaboration units, info mobility channels); • traffic officers.
Constraints	• the monitoring actors shall be able to continuously deliver the gathered data to the Supervisor Centre; • the Supervisor Centre shall have the necessary system infrastructure for both storing and elaborating the data gathered; • traffic officers shall feed the Supervisor Centre with notifications about all scheduled events.
Driving	Pre-trip situation (Before starting the trip); en-route situation (during the trip)

situation	
Vehicle type & state	n.a.
Inefficiency addressed	-
Pre-condition	• The Supervisor Centre is able to collect all traffic and air pollution data from the monitoring actors. • The traffic officer has a clear overview of the current traffic and air pollution situations, and is eventually informed about the adopted contingent action plan.
Post-condition	• The Supervisor Centre is able to properly validate and process all data from the monitoring actors. • The notifications/messages/information introduced by the traffic operators should be clearly visible on the info-mobility channels by the travelers, including drivers. • The traffic operator has to guarantee that the information which are introduced within the system are fresh and consistent.
Main flow	The monitoring actors: • collect traffic and/or air pollution data through proper sensors; • make a first pre-processing/aggregation task of the collected data; • deliver the pre-processed/aggregated data to the Supervisor Centre through pre-defined communication channels. The Supervisor Centre: • receives all the pre-processed/aggregated data from the different road monitoring stations; • validates the pre-processed/aggregated data; • aggregates and elaborates the data in order to extract useful information; • makes available the extracted information on the info-mobility channels; The traffic officers: • insert manual notifications/messages/information in the info-mobility channels; in particular, in the case of need, (i.e. when a specific action plan is actuated) he/she can pilot the messages on the available VMSs (or a subset of them).
Exceptions	-
Reference scenario(s)	• **SC1: monitoring actors providing real-time data about traffic and/or air pollution conditions;** • **SC2: traffic officers evaluating current traffic and air pollution**

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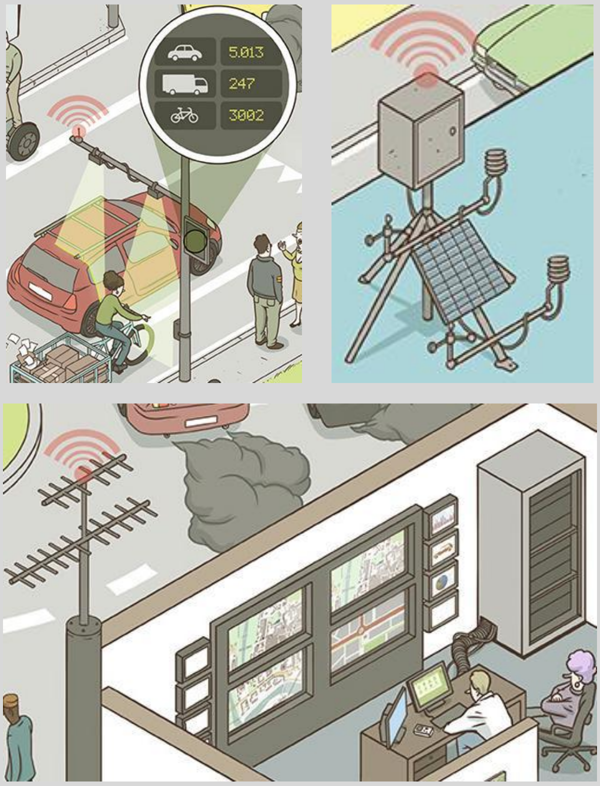
conditions;

- **SC3: traffic officers coordinating info-mobility channels information**



Concerning SC_2, the following tasks are considered:

- **T1: Traffic state estimation**. Traffic data acquired by static traffic detectors and mobile probes are combined together in order to determine a real-time estimation of the traffic conditions in the urban area of interest.
- **T2: Estimation of emissions caused by motorized individual transport**. Traffic data will be even used in order to determine an estimation of the air pollutants emissions produced by traffic in the city.
- **T3: Air quality estimation**. Air pollution data acquired by static air pollution detectors and mobile probes are used within the Supervisor Centre in order to calibrate a dispersion model, which is fed by the estimated emissions, the surrounding conditions data (e.g. meteorological conditions) and eventually by other third parties data (e.g. emissions produced by other sources not related to traffic) in order to create air pollution concentration maps.
</td>
</tr>
<tr>
<td>Dependency with other UCs</td>
<td>-</td>
</tr>
</table>

Table 23: Use case 5 description details.

Name	Traffic controllers adaptive coordination: ACTUATION
Use case ID	UC_6
Version	V01
Author(s)	Paolo Valleri, Roberto Cavaliere (TIS)
Contributing partners	AIT, CBZ
Short Description	Based on the real-time integrated traffic and air pollution overview, the Supervisor Centre can determine very specific preventive and/or reactive action plans in order to (i) properly manage both short term predictable and programmed events and (ii) minimize the impact of unpredictable events. The idea is that based on this improved and integrated overview it is possible to adopt more and more soft countermeasures instead of hard traffic limitation. Doing so, adaptive intelligent control strategies (e.g., dynamic change of traffic actuators like traffic lights, dynamic speed limits, dynamic change in the road networks use, etc.) can be applied avoiding or minimizing the use of severe countermeasures such as traffic circulation limitations.
Goal	The main goal is to apply preventive and reactive control strategies in order to minimize the environmental impact produced by traffic in the urban area of interest, but without significantly influencing other related issues, in particular the road safety.
Actors	• the Supervisor Centre components; • the traffic control systems; • traffic operators.
Constraints	The Supervisor Centre must be able to apply the dynamic strategies on the traffic control subsystems and to inform road drivers, where relevant, about the modified road infrastructure usage conditions (for example, changed speed limits).
Driving situation	Pre-trip situation (Before starting the trip); en-route situation (during the trip)
Vehicle type & state	All types of vehicles.
Inefficiency addressed	• Inefficient routing (INEF_07) • Inefficient driving (INEF_08)
Pre-condition	The action plans are applicable in technological and political terms.
Post-condition	• Drivers are informed about the presence of local variations in the traffic control strategies, and adapt their driving patterns accordingly. • The new traffic control strategies must be accepted by the local

	population.
Main flow	• The integrated monitoring system reveals that a critical situation is appearing in a specific part of the city, or that a traffic / air pollution event has just occurred. • The traffic officers analyze the situation and determine the action plan to be taken. • The traffic control systems are regulated according to the action plan instructions.
Exceptions	Traffic control strategies have to take in consideration safety and user acceptance issues, and the environmental effect that these can produce is therefore limited by these factors. For example, it is not imaginable to keep the traffic light green at an intersection for a very long period of time in order to prioritize traffic on the main road, penalizing too much pedestrians and drivers on secondary roads approaching the intersection.
Reference scenario(s)	• **SC1: traffic officers actuating changes in traffic lights cycles;** • **SC2: traffic officers actuating changes in speed limits;** • **SC3: traffic officers actuating temporary changes in the road network use.** 
Dependency with other UCs	• Traffic and environmental status assessment: INTEGRATED MONITORING (UC_5)

Table 24: Use case 6 description details.

5.3 Use cases interactions

The interaction between the use case is illustrated in Figure 55. It is worth noting that Use Case 5 is a “root” use case, in the sense that all other use cases depend to it. This Use Case does not target any specific inefficiency, but allows other use cases to properly address them.

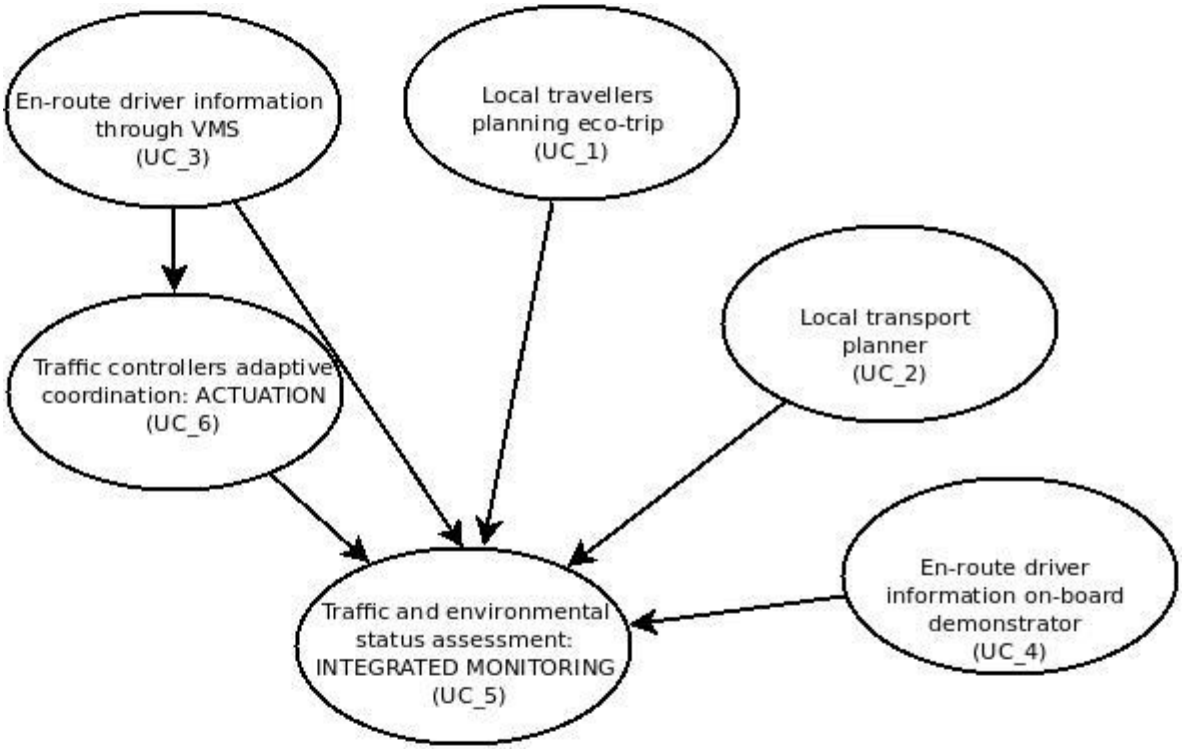


Figure 55: INTEGREEN use cases interactions.

5.4 Use cases and targeted inefficiencies

The relationship between use cases and inefficiencies which are targeted by the INTEGREEN *system* is summarized in Table 25.

	INEF_02	INEF_03	INEF_05	INEF_07	INEF_08
UC_1	X	X	X		
UC_2	X	X			
UC_3				X	X
UC_4				X	
UC_5	n.a.	n.a.	n.a.	n.a.	n.a.
UC_6				X	X

Table 25: Relationship between use cases and targeted inefficiencies.

5.5 Future use cases deployable after INTEGREEN

The INTEGREEN system is in the condition to put the premises for the implementation of future and advanced mobility services based on cooperative technologies, the so-called **cooperative intelligent transport systems (C-ITS)**. An overview of the main research studies available in the international state-of-art is offered in Chapter 6. C-ITS aim to develop a connected transport system in which all main actors – traffic management centers, roadside units, vehicles and travelers – are connected together seamlessly in order to maximize the collection of transport-related data coming from the road and the possibility to rapidly exchange the information of interest between the nodes of the system.

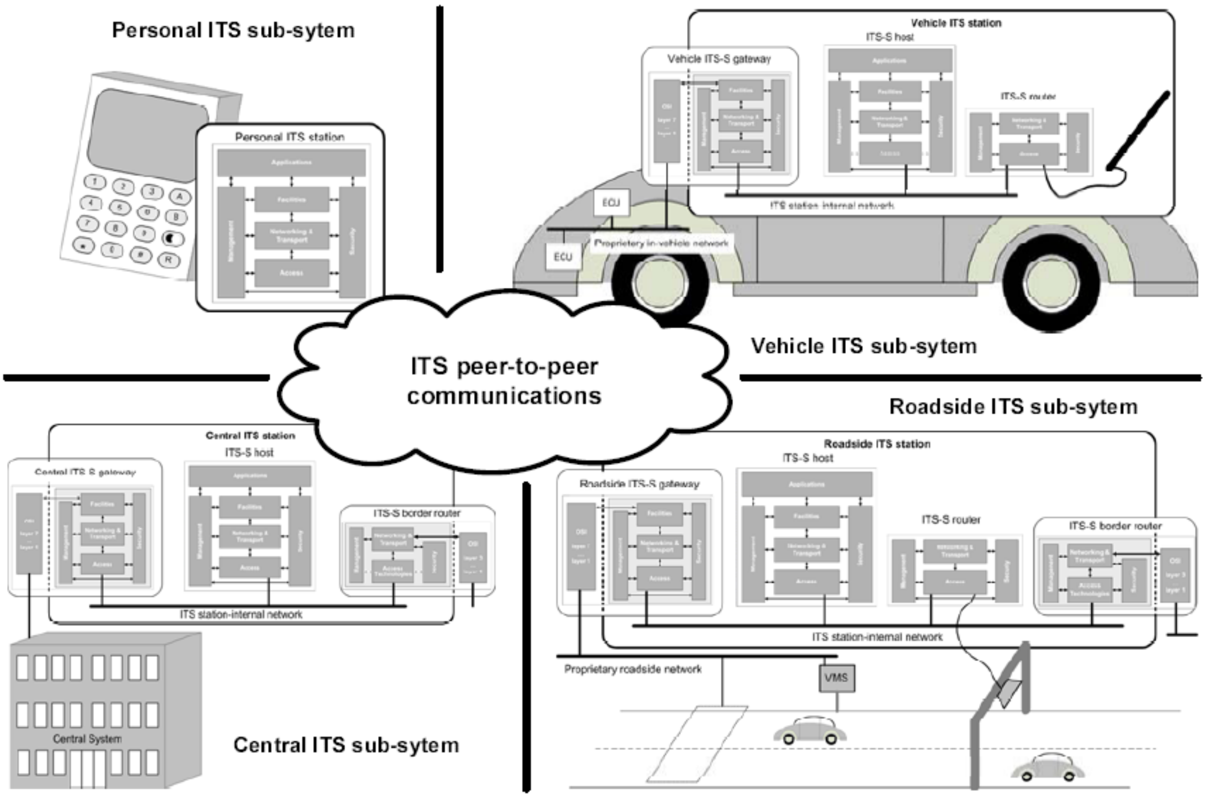


Figure 56: The reference architecture for C-ITS [29].

Given these premises, C-ITS will allow travelers to further increase the spatial and temporal horizon of their information about the current status of the local transport network, and thus to further optimize their travel decisions, in order to address global challenges such as traffic congestion, air pollutants and greenhouse gases emissions, and road safety.

A natural extension of the mobile INTEGREEN system is to **monitor vehicular emissions** by introducing for example an additional component connected to the on-board unit, and to provide this data to the Environmental Supervisor Centre, where all this data can be aggregated and analyzed. This will allow policy makers to introduce smart incentives to drivers having a green driving behavior, for example by offering differential fuel prices, and thus to further incentivize eco-driving behaviors in local travelers. This is a crucial point, since relevant changes are likely to be obtained by rewarding virtuous travelers instead of punishing unworthy ones.

Such use case could produce an evolution of use case UC_2; local fleet managers could be in the condition to have a further optimization of their resources, while the traffic management centers will have the possibility to introduce advanced strategies in the **management of trips**

of heavy pollutant vehicles; for example, the details of a trip could be arranged cooperatively by identifying the solution which has the minimum impact on traffic and environment and which satisfies the commercial needs of fleet managers.

New use cases (and business models) are possible even in the insurance industry. For example, premiums can be spread out across drivers profiles based not only on the number of kilometers a vehicle has covered ("***pay-as-you-drive***"), but also on the base of the driving pattern of its drivers – so introducing a "***pay-how-you-drive***" approach.

All this scheme based on awards and incentives must however take in consideration (and monitor) all the multi-modal trips performed by a traveler, i.e. not only the ones made by car. The incentives should be designed in a way to foster **intelligent multi-modality**, and to let people take those travel decisions which best fit with the current requirements on traffic and environment.

6 INTEGREEN system concept

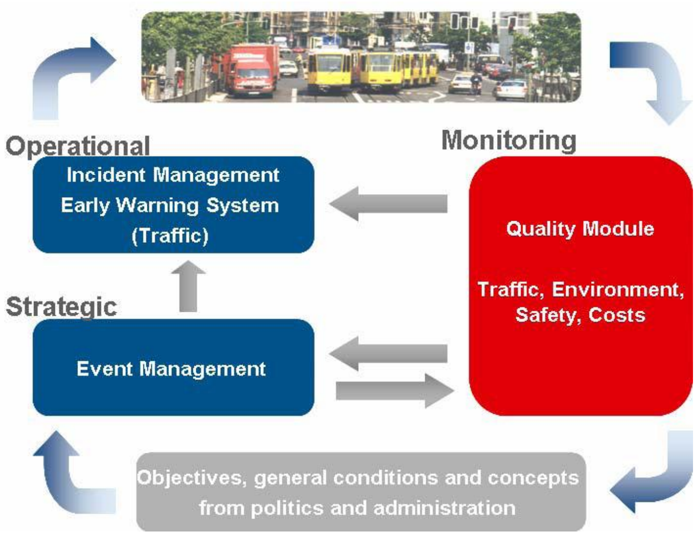
This chapter introduces the functional concept of the INTEGREEN system, which is defined in order to match (i) the expectations of local stakeholders and needs, (ii) the targeted inefficiencies during the pre-trip and en-route travel phases, and (iii) the reference use cases. A fourth factor which is considered in this work of analysis is the evaluation of the international state-of-art, which is a fundamental aspect in order to let the system architecture be compliant with other architectures which are proposed in order to address similar challenges.

In the next pages a review of the most important research projects in the field of the "environmental traffic management" topic is introduced. The objective of this analysis is not specifically to be exhaustive, but is more to give an insight of the most important aspects which must be considered in the functional definition of the INTEGREEN system concept, and later in the identification of the related requirements.

6.1 International initiatives state-of-art

6.1.1 iQmobility – a research project in Berlin

„iQ mobility – Integrated Quality and Mobility Management for Road Traffic in the Berlin Region" was a joint research project started in 2004 being undertaken by various partners from the federal states of Berlin and Brandenburg [30].



The aim of this research project was to improve the quality of road traffic on the existing road network in the whole region by using intelligent traffic control measures. Research emphasis was put on several aspects for traffic control optimization, and in particular novel quality criteria such as air pollution and noise (as well as road accidents) were considered besides basic traffic parameters (i.e. flowing traffic, congestion, and travel times). The overall mobility management system which was proposed in the project is structured as a control loop with the following modules:

- the **Quality Module**, which continuously monitors and evaluates the quality of road traffic;
- the **Strategic Traffic Management** module, which takes care of predictable events such as large scale events and construction sites;

- the **Operational Traffic Management** module for the early detection and reaction to traffic "events" (e.g. car incidents).

One of the research lines of iQmobility brought to the development of the IMMIS^{mt} system, which allows to monitor the distribution of the pollutants over a monitored area by means of a combination of air quality models fed by traffic, weather and air pollution concentration data. The system architecture of IMMIS^{mt} is presented in Figure 57.

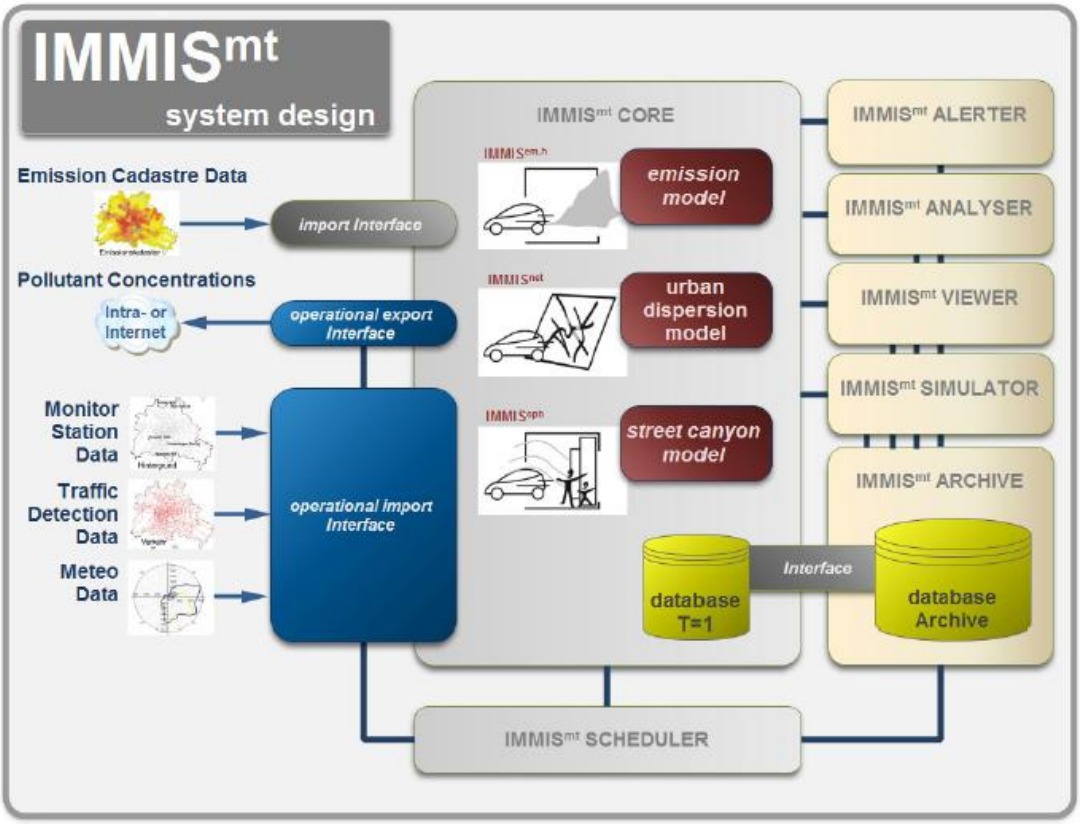


Figure 57: The architecture of IMMIS^{mt} system developed within iQ mobility project [30].

The IMMIS^{mt} system was started to be empirically evaluated in 2008. In particular, a field test called "Environmental Traffic Management" was carried in a typical street canyon within the city centre of Berlin, with the objective to analyze the efficiency of traffic management measures implemented for the reduction of traffic induced pollution by fine particles (e.g. carbon, particulate matters) and nitrogen oxides (NO_2). For this purpose, dynamic operational control measures such as traffic lights phases changes were specifically tested.

The results clearly demonstrated that the reduction of traffic jams and the increase of constant flowing traffic can significantly reduce air pollution levels. A combination of traffic management measures demonstrated the capability to reduce NO_2 levels up to 17%, while the reduction gain was assessed to be lower in the case of particulate matters because of the high urban background pollution in the area under investigation.

6.1.2 *Carbotraf - a Decision Support System for environmental traffic management*

Carbotraf ("*A Decision Support System for Reducing CO_2 and Black Carbon Emissions by Adaptive Traffic Management*") is a research project co-funded by the European Commission under the FP7 program, which has the specific objective to study the inter-relationships between traffic states and CO_2 and Black Carbon (BC) emissions, which strongly depend on the particular flowing conditions of vehicular traffic [31] . Indeed, BC is the second most important greenhouse factor and a pollutant implicated in several studies on health. The main goal of the project is to develop a decision support system (DSS) for online prediction of emission levels, whose architecture is presented in Figure 58.

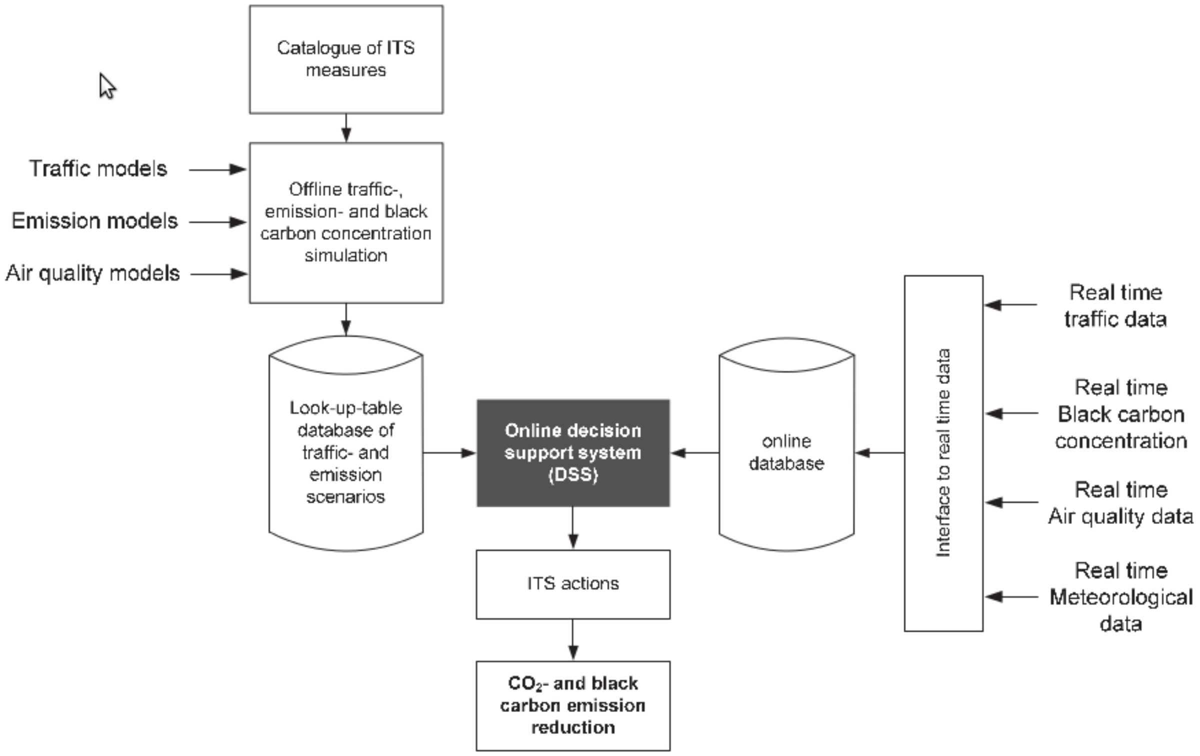


Figure 58: The architecture CARBOTRAF decision support system [31] .

The system aims at (i) aggregating all relevant information data coming from different sources such as real-time traffic information delivered by existing sensors, novel technology vision sensors, air quality sensors and other additional data sources (e.g. weather conditions), and (ii) integrating different traffic, emission and air quality models, that can support the development of low-emission traffic scenario that can be achieved by imposing several, articulated ITS measures, such as re-routing and adjustment of traffic light sequences. An empirical validation phase of the proposed DSS is going to be carried out in the urban areas of Graz (in Austria) and Glasgow (in the United Kingdom).

6.1.3 eCoMove – the reference research project for energy-efficient cooperative mobility services

eCoMove ("*Cooperative Mobility Systems and Services for Energy Efficiency*") is probably one of the most important on-going research projects co-funded by the European Commission under the FP7 in the field of cooperative ITS (C-ITS) [32]. The objective of this project is to achieve a cleaner and more energy-efficient mobility of goods and people by specifically tackling energy inefficiencies in three different domains, i.e.:

- **drivers' behavior**, by introducing a virtual coach which does not only advice to adapt driving behaviour for minimum fuel use but also gives personalized recommendations based on individual driving historical records;
- **route choice**, by creating an application tool which can be applied for both people and goods transport and which can allow to plan the trip in advance and/or adapt the current trip on-demand by discovering the real-time lowest energy route;
- **traffic management**, by developing a distributed platform which is able to optimize traffic lights phases and apply other traffic control measures leveraging on the latest vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication technologies.

In order to address these targets, eCoMove proposes an integrated and innovative system architecture () composed of the following core technologies:

- a **communication platform**, which relies on V2V and V2I communication technologies;
- a set of ***eco messages*** distributed among different mobility participants, in particular:
    - ✓ eco-floating vehicle data about vehicle's progress, destination and fuel consumption, which is collected and disseminated to other vehicles and the traffic control centre;
    - ✓ eco-traffic situational data about the traffic conditions, which is sent from the infrastructure to vehicles;
- a digital **ecoMap**, which is enhanced with static and dynamic attributes needed for eco-driving support, such as slope, historical speed profile and energy consumption data but also traffic data and information about other vehicles;
- an **ecoSituational model**, which is used at a microscopic level to determine the optimal driving strategy to be taken into account based on (i) the vehicle's driving behavior and the dynamics of nearby vehicles; (ii) the current traffic situation, and (iii) the fuel consumption, predicting how this will evolve in the reaction horizon of the driver;

- an **ecoStrategic model**, which allows to translate at a macroscopic level the knowledge about high fuel consumption factors included in the ecoSituational model to the entire road network, as a basis for the traffic management and control strategies.

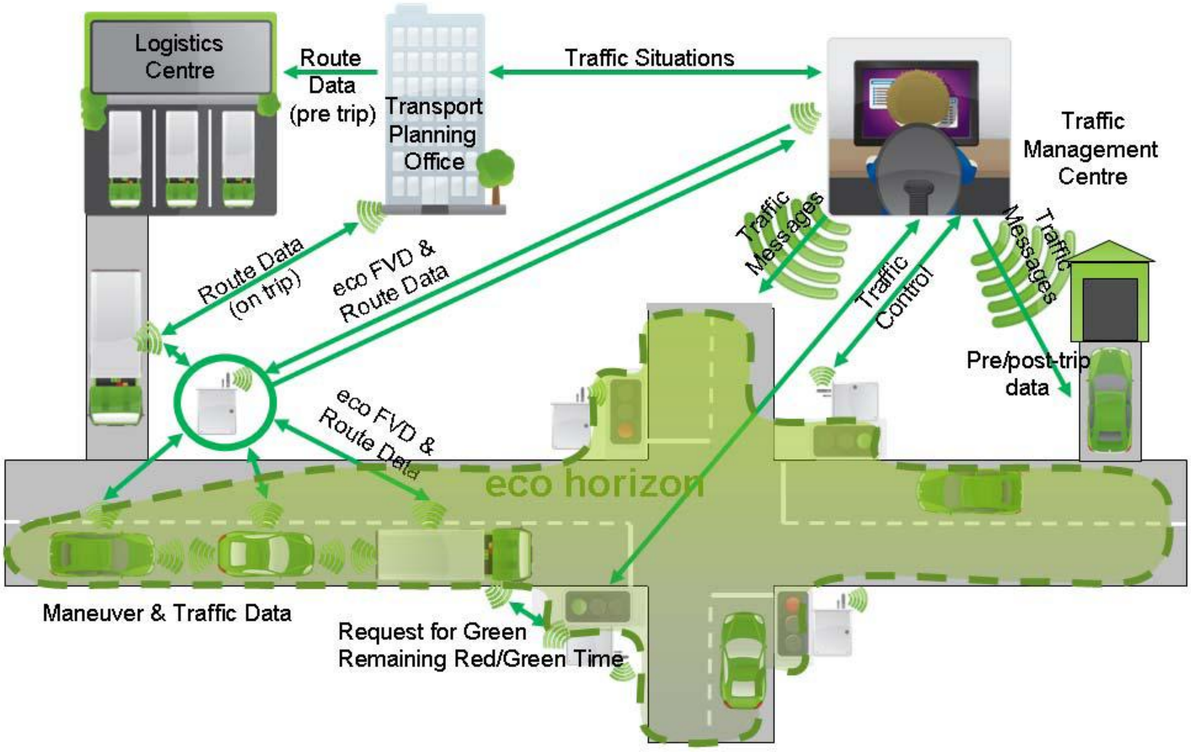


Figure 59: The high-level system architecture of the eCoMove project [21].

The objective of the project is to demonstrate that a similar approach is in the condition of reducing by 20% fuel consumption and therefore CO_2 emissions (Figure 60).

6.1.4 COSMO – a pilot for cooperative mobility systems

COSMO ("*Co-operative Systems for Sustainable Mobility and Energy Efficiency*") is one of the main pilot projects in Europe aiming to (i) demonstrate in realistic conditions the benefits of cooperative mobility services and (ii) to quantify their impact on increasing the energy efficiency of transport [33]. The project is co-funded by the European Commission under the Competitiveness & Innovation Programme – ICT Policy Support Programme (CIP – ICT-PSP).

Three pilot test site areas – Salerno (Italy), Vienna (Austria) and Gothenburg (Sweden) – are testing in real conditions a set of cooperative mobility applications, in order to produce a comprehensive evaluation of their performance from a technical, practical and organizational point of view. In particular, the following application areas are covered:

- **Eco-traffic management & control**. Traditional ICT systems adapt traffic control to reduce journey times and fuel consumption. In COSMO, these traditional strategies

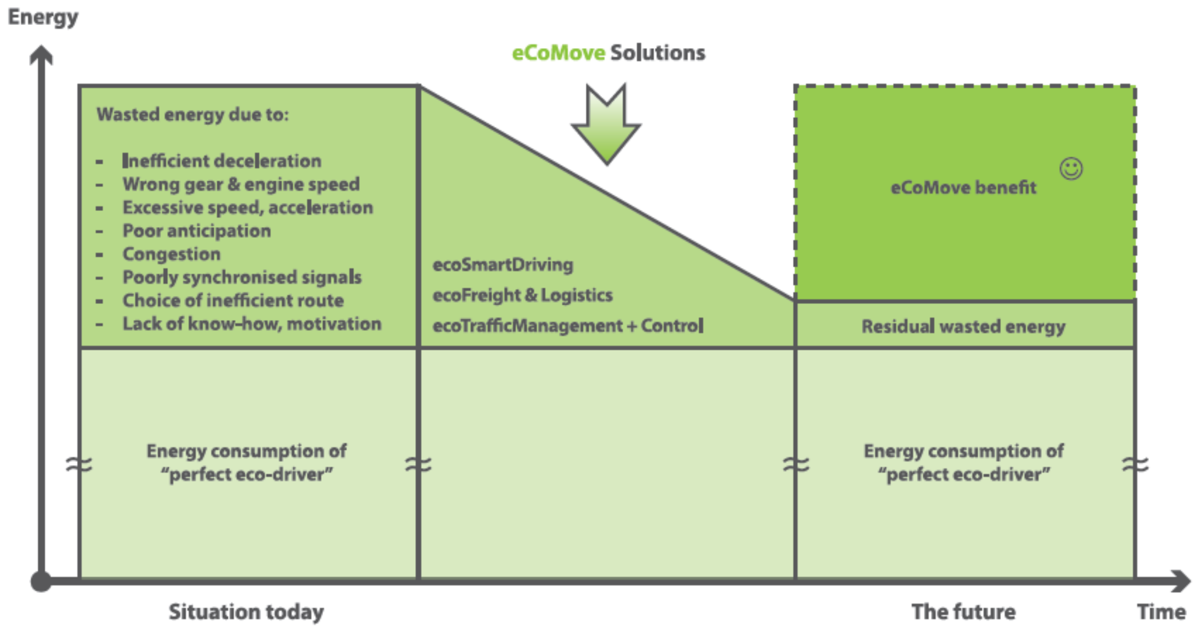


Figure 60: The overall vision of eCoMove project [32].

are also enhanced by means of (i) cooperative systems and (ii) a traffic-sensitive street lighting strategy which dynamically adjusts the level of luminosity of the street on the base of traffic density (Figure 61).

- **Eco-driving support**, i.e. the possibility for the driver to be permanently reminded of deviations from the optimal path and advised with recommendations to minimize the fuel consumption of his/her vehicle. This enhanced horizon is made possible thanks to a direct interaction with the central traffic management system.

- **Eco-access management**, i.e. the approach to dynamically limit the access to specific city areas on the basis of (i) current pollution emission levels and (ii) the environmental impact produced by a single vehicle, based on its EURO emission class.

6.1.5 ecoDriver – a research project for energy-efficient driving coaching applications

ecoDriver ("*Supporting the driver in conserving energy and reducing emissions*") is a research project co-funded by the European Commission under the FP7 program, whose purpose is to develop new technologies for both in-vehicle and remote devices, such as downloadable smartphone applications, that will help drivers to significantly reduce their fuel consumption by driving in a more energy-efficient way [34]. More specifically, the project aims to maximize system effectiveness and acceptance by adapting eco-driving human-machine interfaces (e.g. graphical interfaces, haptics, voice messages, etc.) to the driving style (e.g. relaxed vs. sportive), the traffic conditions (e.g. fluid vs heavy traffic), to the considered powertrain (e.g. conventional, hybrid, electrical) and vehicle type

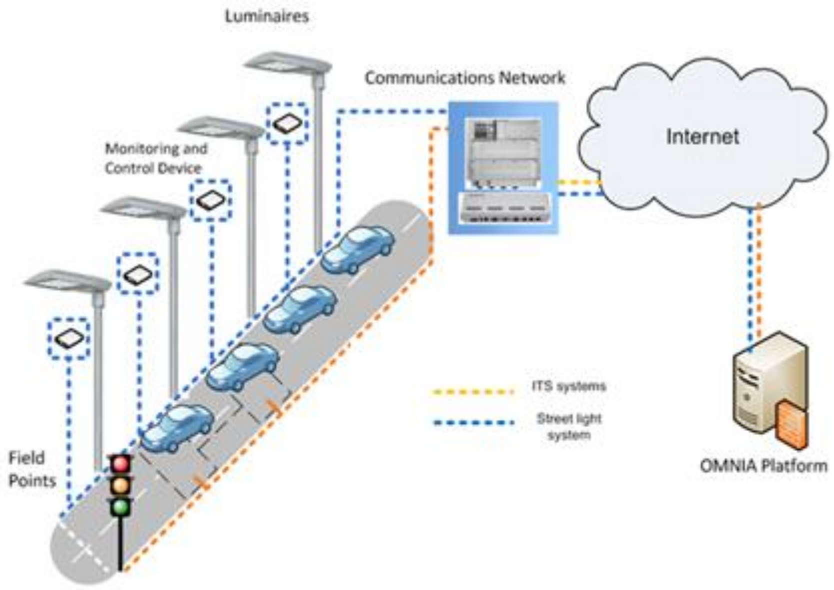


Figure 61: The traffic-sensitive street lighting system of COSMO [33].

(e.g. passenger cars, vans, trucks, buses, etc.), all this without jeopardizing overall driving safety.

Figure 62: An overview of the use scenarios targeted by ecoDriver [35].

6.1.6 EcoNav – a concept of ecological aware navigation

EcoNav (“*Ecological Aware Navigation: Usable Persuasive Trip Advisor for Reducing CO_2 Consumption*”) is a research project co-funded by the European Commission under the FP7 program whose vision is to minimize the fuel consumption by providing intelligent and personalized navigation advices to drivers [36]. The project aims to demonstrate that a similar approach, based on the idea to continuously use on-board navigation systems to teach drivers on how to save fuel at every turn, can lead to up 30% of CO_2 emissions reduction. The most interesting novel features which are introduced in the scope of the project in the field of road navigation are (Figure 63):

- the minimization of the needs for explicit user input, which is possible by:
  - ✓ integrating automated travel mode detection based on real-time GPS data into the trip planning;
  - ✓ detecting users trip purpose through the analysis of behavioral patterns;
  - ✓ building user models to personalize advices on the base of prior and individual choices;
- the development of advanced door-to-door emissions models that provide accurate feedback on the ecological footprint and exposure levels during both pre-trip as well as during travelling and car driving activities;
- the adoption of persuasive interface strategies to give feedback about the ecological impact of individuals behavior.

Figure 63: The eco-navigation system proposed by EcoNav [36].

6.1.7 Amitran – a holistic methodology for transport CO_2 emissions estimation

Amitran (“*Assessment Methodologies for ICT in multi-modal transport from User Behaviour to CO2 reduction*”) is a research project co-funded by the European Commission under the FP7 program whose vision is to propose a reference methodology to correctly estimate well-to-wheel emission reductions applied to the transport sector [37]. The mobility system has numerous components (driver, vehicle, infrastructure, traffic centre, operator, etc.) and stages (energy production, vehicle operation, maintenance, etc.), each with an associated carbon footprint. The aim of Amitran is specifically to develop a framework for evaluation of the effects of ICT measures in traffic and transport on energy efficiency and CO_2 emissions, and as a consequence to contribute in the development of ICT solutions that are in the conditions to provide more efficient multi-modal transport of goods and passenger mobility.

Amitran is going not only to design open interfaces for models and simulation tools implementing the project's methodology, but also to establish a generic scaling up methodology and to build up a publicly available database, which can be useful in order to spread its adoption at an European level. The proposed methodology will be validated among different use-cases by using data available from other projects or studies, with the objective to become a reference instrument by future projects in the field. The main novelty of Amitran is in its intention to consider all transportation system in a holistic approach, whereas latter tools are usually only concentrated on specific components of it.

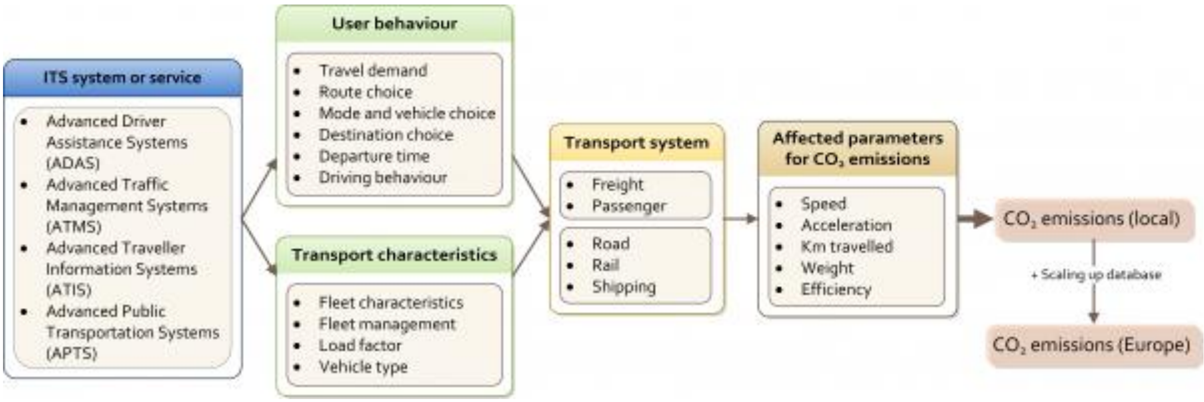
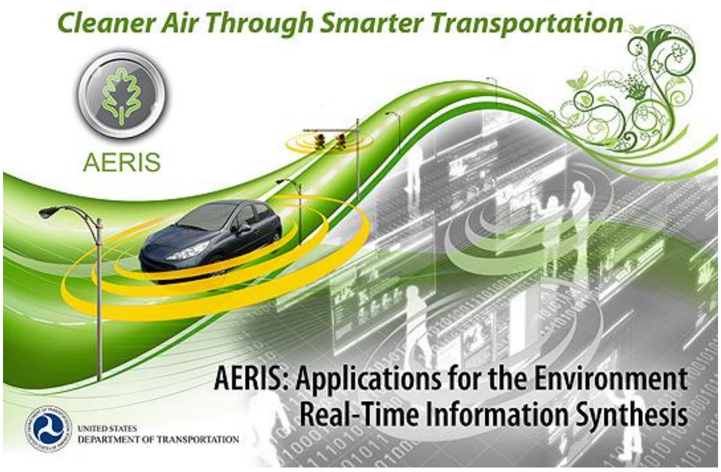


Figure 64: The holistic CO2 emissions methodology proposed by Amitran [37].

6.1.8 A glance to USA: the AERIS program



"*Applications for the Environment: Real-Time Information Synthesis*" (**AERIS**) is the "green" research component of the multi-modal research initiative of the Intelligent Transportation Systems Joint Program Office (**ITS JPO**) within the U.S. DOT Research and Innovative Technology Administration (**RITA**) [31]. The overall goal of this organization is to evaluate the potential of advanced applications relying on cooperative mobility systems, and assess how they can enhance in practice current operational practices.

In particular, the AERIS program has been introduced with the aim to deploy interoperable technologies and applications that have as a specific target the reduction of the negative impacts of transportation on the environment. The AERIS Program intends specifically to assess how the suite of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication technologies may contribute to improvements in air quality, greenhouse gas reductions, and fuel savings. The focus is put on a set of "**transformative concepts**", namely (i) **eco-signal operations**, (ii) **dynamic eco-lanes**, (iii) **dynamic low-emissions zones**, (iv) **support of alternative fuel vehicle operations**, (iv) **eco-traveler information** and (vi) **eco-integrated corridor management**. Each transformative concept includes a certain number of reference applications, as summarized in Table 26.

Transformative Concepts	Applications
Eco-Signal Operations	1. Eco-Approach and Departure at Signalized Intersections 2. Eco-Traffic Signal Timing 3. Eco-Transit Signal Priority 4. Eco-Freight Signal Priority 5. Connected Eco-Driving
Dynamic Eco Lanes	1. Dynamic Eco-Lanes 2. Eco-Speed Harmonization 3. Eco-Cooperative Adaptive Cruise Control 4. Eco-Ramp Metering 5. Connected Eco-Driving 6. Multi-Modal Traveler Information
Dynamic Low Emissions Zones	1. Dynamic Emissions Pricing 2. Connected Eco-Driving 3. Multi-Modal Traveler Information
Support for Alternative Fuel Vehicle Operations	1. Engine Performance Optimization 2. AFV Charging / Fueling
Eco-Traveler information	1. Dynamic Eco-Routing 2. Dynamic Eco-Transit Routing 3. Dynamic Eco-Freight Routing 4. Eco-Smart Parking 5. Connected Eco-Driving 6. Multi-Modal Traveler Information
Eco-Integrated Corridor Management	1. Eco-Integrated Corridor Management Decision Support System

Table 26: The list of applications under evaluation within the AERIS research program.

6.1.9 *Other relevant research projects*

Other research projects are worth to be considered in this state-of-art analysis. The following pages provides a short insight on them.

CVIS, COOPERS and SAFESPOT

CVIS, COOPERS and SAFESPOT are actually the European research projects which have introduced the concept of cooperative mobility.

More specifically, **CVIS** ("*Cooperative Vehicle Infrastructure systems*") has designed, developed and test the **core technologies** which are needed to allow cars to communicate with each other and with the nearby roadside infrastructure, and thus to enable a wide range of potential cooperative services to run on an open application framework in the vehicle and roadside equipment [39]. The project introduced an open architecture and system concept which is the basis of all the first C-ITS standards, and firstly addressed potential issues such as user acceptance, data privacy and security, system openness and interoperability, risk and liability, public policy needs, cost/benefit and business models, as well as roll-out plans for implementation.

On the other side, **COOPERS** (*COOPerative SystEms for Intelligent Road Safety*) concentrated its attention on the definition, development and test of the first cooperative mobility services, equipment and applications using two-way communications between road infrastructure and vehicles (V2I) from a **traffic management perspective** [40]. In parallel, **SAFESPOT** ("*Cooperative systems for road safety "Smart Vehicles on Smart Roads*") introduced the concept of *safety margin assistant system*, which strongly relies on vehicle-to-vehicle communications (V2V) in order to extend in space and time drivers' awareness and thus to increase the capability in detecting potentially dangerous situations in advance [41]. In this **vehicle-perspective** scenario, vehicles, including cars, trucks, and motorbikes, as well as roadside units are both source and destination of safety relevant information, in a lot of reference safety use scenarios.

FREILOT

FREILOT (*Urban Freight Energy Efficiency Pilot*) is a FP7 project concluded in 2011 which represents a milestone in the European research in the field of energy-efficient freight transport services on the urban roads [44]. The project developed an holistic architecture based on cooperative technologies which involves traffic managers, fleet managers, delivery vehicles and drivers, and demonstrated in four different test sites (Helmond, Lyon, Bilbao and Krakow) how this kind of approach can produce up to 25% reduction of fuel consumption.

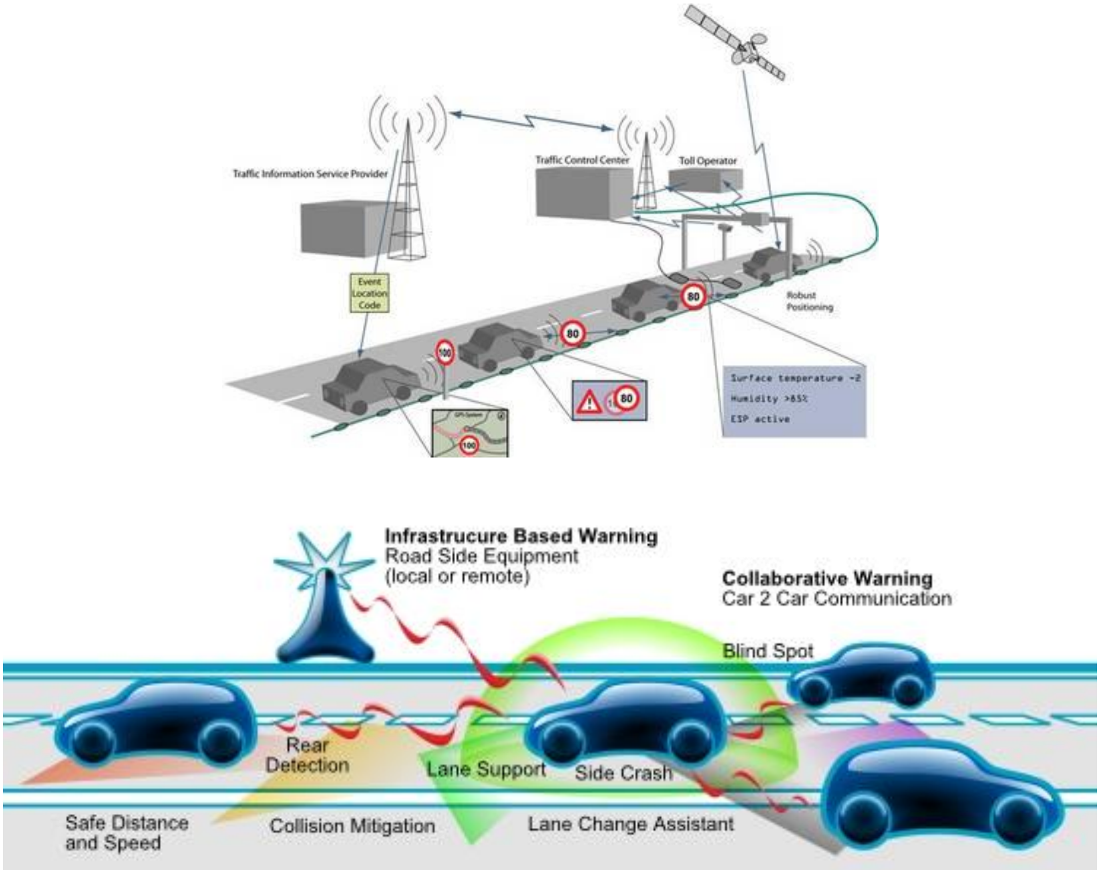


Figure 65: The system concepts of COOPERS (above) [40] and SAFESPOT (below) [41].

Four main applications were proposed within the project, namely (i) **ECO Driving Support**, i.e. a virtual support for eco-trips; (ii) **Delivery Space Booking**, for the real-time management of the delivery spaces; (iii) **Energy Efficient Interactions**, which aims to optimize the way freight delivery vehicles approach traffic light intersections from an energy-efficiency point of view; and (iv) **Acceleration Speed Limitation** for the automatic speed control of these delivery vehicles (Figure 66).

Figure 66: The main applications developed within FREILOT research project [42].

Niches+

Niches+ (New and innovative concepts for helping European transport sustainability – towards implementation) is a FP7 project built on the success of its predecessor, Niches, aiming at stimulating the promotion of new innovative concepts for urban transports between stakeholders of different sectors. The project produced a set of recommendations for both research and policy makers covering four complementary thematic areas, i.e.:

- innovative concepts to enhance accessibility;
- concepts for efficient planning and use of infrastructure and interchanges;
- traffic management centers, with a specific focus on (i) mobile travel information services for the public and (ii) the integration of environmental pollution data in traffic management
- automated and space efficient transport systems.

CATCH

CATCH (*Carbon aware travel choices in the climate-friendly world of tomorrow*) is a FP7 project concluded in 2012 aiming at developing a knowledge platform and an integrated set of tools able to foster carbon reduction policies into the public's and policy maker's decision making [43]. The tools were developed and designed in order not only to (i) support city stakeholders to develop sustainable transport policies and plan (SUMPs), but also (ii) to motivate travelers to adopt sustainable transport choices. More specifically, the visual tools enable users to understand the carbon consequence of their mobility choices, and allows decision-makers to simulate and visualize future urban scenarios.

The project even investigated how people respond to different presentation formats of CO_2 information with consideration to both understanding and motivation to reduce car use. The research focused not only on the information presentation aspects, but also on non-environmental motivations that can lead to a shift in the travelers' needs and perspective.

ECOSTAND

ECOSTAND is a coordination action which aims to create a common assessment methodology and a joint research agenda with Japan and the USA on ITS applications which focus specifically on energy efficiency and CO_2 reduction [44]. The objective of this action is in particular to (i) formulate on one side a roadmap defining the different steps that need to be taken in order to reach such an agreement and (ii) determine a joint research agenda aiming at identifying research gaps and proposing solutions that can enable the development of the methodology.

COMPASS

COMPASS (*Optimized co-modal passenger transport for reducing carbon emissions*) is an on-going research project co-funded by FP7 program aiming at identifying (i) key demographic, societal and economic trends that are changing mobility paradigms, and (ii) the mobility needs of current and future travelers [45]. One central point is to assess the potential role of ICT on one side in promoting co-modality and putting the basis for an optimized and CO_2 efficient co-modal transport system, and on the other side in influencing mobility patterns, in particular for long-distance travels.

6.2 INTEGREEN system architecture description

The evaluation of the international state-of-art has provided a large number of valuable inputs for the definition of the INTEGREEN system architecture, even in terms of future exploitation opportunities based on advanced C-ITS technologies. The architecture which is proposed in this section takes in consideration all elements which are directly or indirectly part of the INTEGREEN system. The advantage of this holistic approach is that all factors and components at the Supervisor Centre are taken into account, giving the possibility to (i) maximize the efficiency of the proposed INTEGREEN innovation, even in the perspective of future exploitations, and (ii) minimizing the risk for possible interoperability barriers.

Figure 67 presents the reference system architecture, mapping the high-level system components described in the project proposal. The architecture, together with the requirements list introduced in the chapter, is *de facto* the operational basis for the consolidation of the successive design and implementation activities.

The architecture is composed of three main different layers:

- the **data-sources layer**, i.e. the layer which is in charge of properly collecting all relevant data from the *sources* on the road infrastructure;

- the **data center layer**, which is in charge to store and process the collected data by means of an integrated data mining approach;

- the **front-ends layer**, which is in charge to deliver all relevant processed data to the *end-user clients*.

More specifically, the following definitions are introduced:

- *a **data-source** represents a single and unique point in charge of providing a consistent API for the retrieval of a well-defined class of **raw data** (i.e., vehicle cinematic data, air pollution data, etc.) from arbitrary sources (i.e., environmental stations, traffic monitoring stations, etc.) over a variety of supported protocols at different layers of the ISO/OSI reference stack.*

- *a **front-end** represents a single and unique point in charge of providing a consistent API for the distribution of a well-defined class of **elaborated information** to arbitrary*

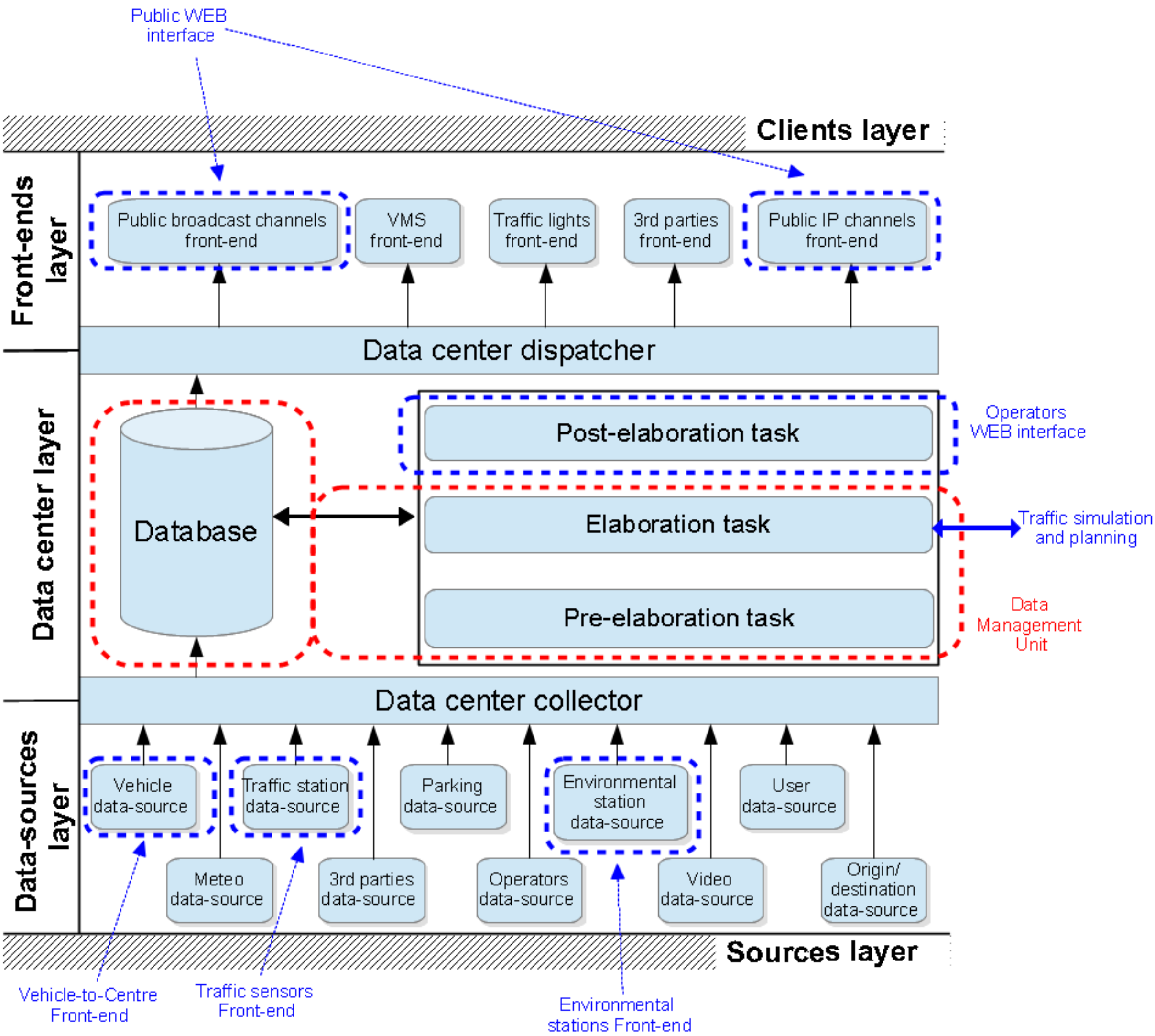


Figure 67: The reference system architecture of the Supervisor Centre of INTEGREEN.

clients through well-defined interfaces. Moreover it forwards requests toward the back-end data center collector to get requested data or to perform a requested service.

The access to the data center layer is possible from one side through the **data center collector**, which is the unique collection point of all the data collected by the data sources, and on the other side through the **data center dispatcher**, which has to transparently (i) manage the different requests of the several front-ends and (ii) provide them the accessible information which are stored in the data center layer.

More details about the expected functionalities of each component of the system architecture are provided in the last chapter of this report.

7 Requirements identification

The objective of this last chapter is to finally consolidate the reference system requirements of the INTEGREEN system. The requirements are basically divided in:

- **functional requirements**, which define *what* the system is supposed to do, and capture a specific function the system should provide;
- **non-functional requirements**, which defines *how* the system is supposed to be. These requirements are qualities related to functions such as performance, scalability, accessibility, extensibility, maintenance and so on.

It is worth noting that a separate deliverable (D.2.2.1 – “Mobile system requirements”) provides a similar analysis for the mobile system of INTEGREEN. The mobile system is an automotive electronic platform placed on board of a probe vehicle which is equipped with a telematic unit, a traffic monitoring unit and an environmental monitoring unit. The vehicle data source will collect the data provided by a fleet of these probe vehicles by interfacing with the vehicle-to-centre front-end. For more details please refer to the section of this chapter illustrating the requirements of the vehicle data source.

The requirements description follows the structure of Table 27. A clear definition of requirements will not only help to monitor project progress and assess possible deviations from the initial plans, but will also simplify such evaluations.

ID	[Component acronym]-[numeric identifier]
Name	Understandable name
Description	Short description containing the intention of the requirement
Rationale	Justify the requirement presence
Type	Functional requirements / Non-functional requirements / Interfaces/Performance
Priority	**M** (must) / **S** (should) / **C** (could) / **W** (won't have)

Table 27: Requirement template.

The ID field is the identification and lets us to identify the requirements throughout the whole document. The alphabetic part represents the acronym of the involved component while the numeric part is the actual progressive number of the requirement belonging to the specific component. Moreover the name field comes for a better human readability whereas the description field is in charge of providing a textual description containing the desired results although it might avoid to say anything about how the requirement can be technically satisfied. In addition the rationale field explains a short but fundamental reason of why such requirement is needed.

The requirement type refers not only to the aforementioned functional / non-functional categories, but puts into evidence even if a specific non-functional requirement is:

- an **Interface** requirement, in order to highlight the presence of an interaction between components, modules, or other system parties;

- a **Performance** requirement, which highlights the presence of quantitative constraints.

The priority field defines the requirement prioritization following the MoSCoW prioritisation technique [46]. This technique divides the requirements into four different categories:

- **M – Must have**. Critical requirements, which have to be included in the system in order to consider the project implementation successful.
- **S – Should have**. Important requirements but less critical for overall project implementation success.
- **C – Could have**. Potential requirements to increase customer satisfaction for little cost but they are not critical for project implementation success at all.
- **W - Won't have (but Would like)**. These requirements are not going to be implemented in the project schedule, but they may be taken into account for further developments.

The requirements are presented in distinct sections, one for each layer presented in the Supervisor Center architecture. Each section is introduced by a list of requirements that are shared by all the components belonging to the reference layer, and is split in one or more subsections which introduce specific constraints that apply only to the component under investigation. In case of overlapping requirements applying to the same component, a reference role based on a hierarchical criterion is applied, i.e. the requirement which is defined at the most specific level (e.g. the single component) takes the precedence over the others (e.g. the reference layer or the system as a whole).

7.1 Definitions

In order to properly understand the contents of each single requirement, a set of definitions is introduced. These definitions complete the definition of data-source and front-end which were introduced in the previous chapter.

- **Interface**: refers to a point of interaction between components. The interaction with the other party is made possible through well-defined exposed functionalities.
- **Window observation**: a time interval which is needed from an arbitrary source to obtain as output a raw data which is representative for the observed phenomena in the reference temporal period.
- **Monitoring instant**: refers to the ending instant of a window observation.
- **Generated data**: the output produced by an arbitrary source at the end of a window observation, i.e. that is ready at the monitoring instant.
- **Elaboration time interval**: the time interval which is needed to integrate the generated data in the overall, central elaboration chain and to possibly update the

generated information.

- **Generated information**: the processed information which is the output of the elaboration chain performed by the Supervisor Centre components and is available at the end of the elaboration time interval.

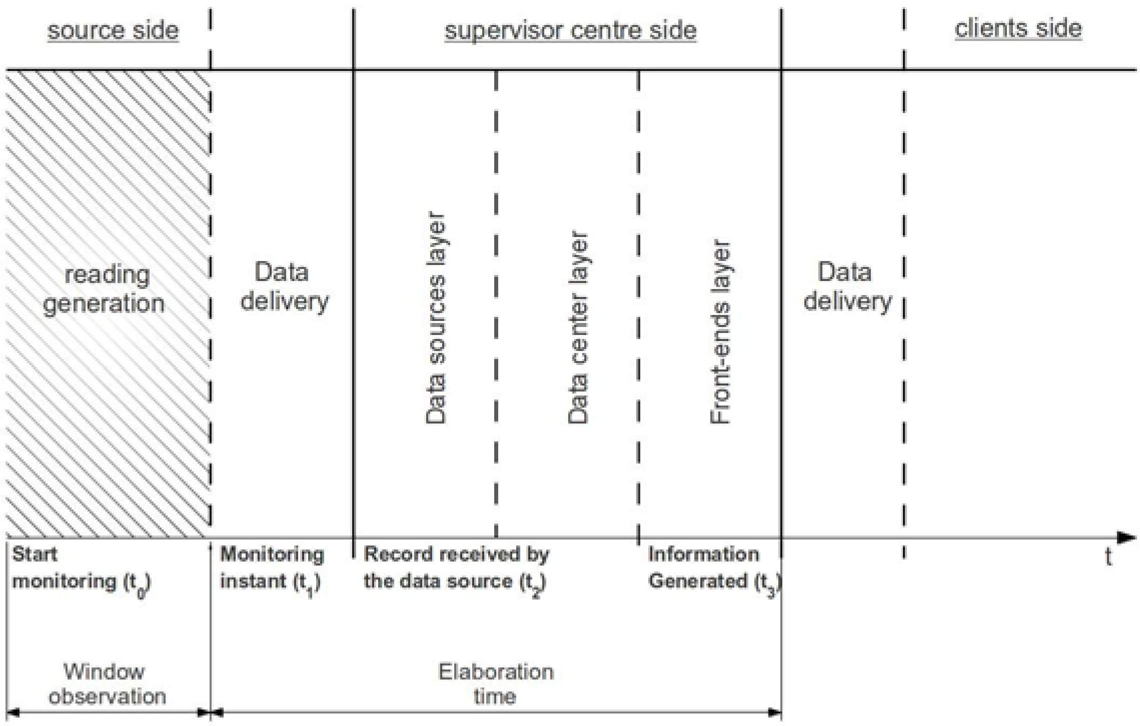


Figure 68: Graphical representation of "window observation" and "elaboration time interval" definitions.

- **Layer**: a way of hiding the implementation details of a particular set of functionality (Figure 69).

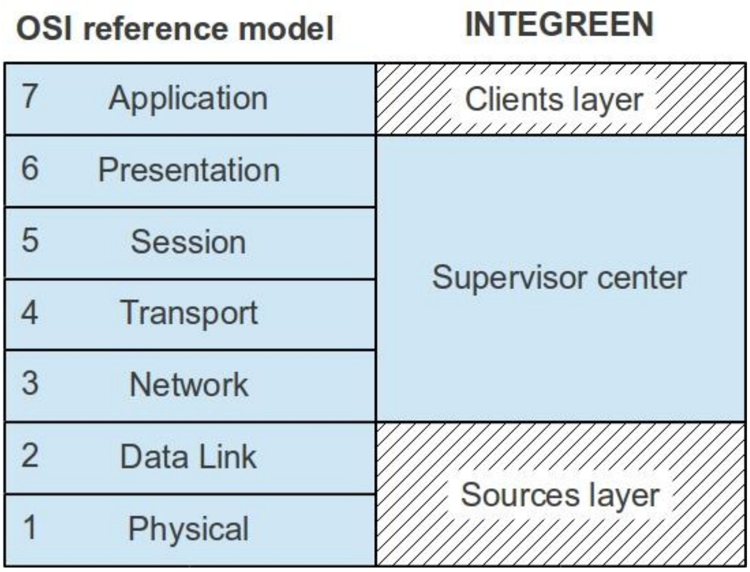


Figure 69: Graphical representation of “layer” definition.

- **Vehicles gap**: is a temporal distance between two vehicles defined as the time required by the head part of the car behind to reach the back of the car ahead.

- **Vehicles headway**: is a temporal distance between two vehicles defined as the time required by the head part of the car behind to reach the head of the car ahead.

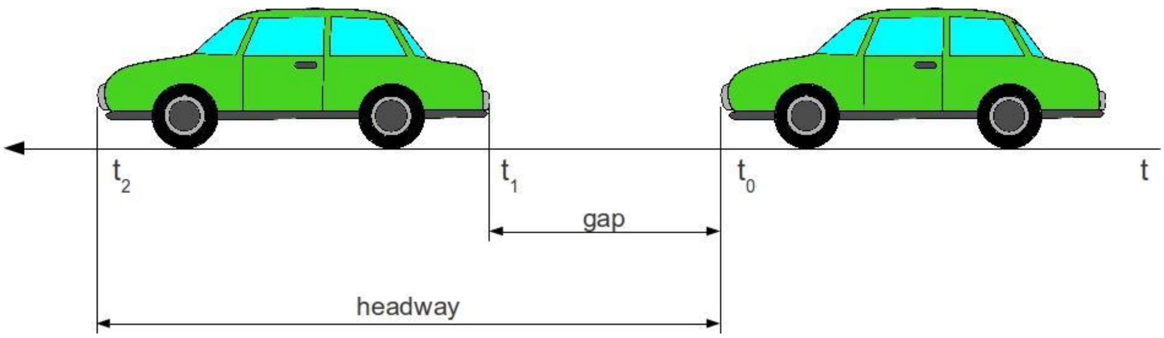


Figure 70: Graphical representation of “vehicles gap” and “vehicles headway” definition.

- **Timestamp**: is a sequence of characters or encoded information identifying when a certain event occurred, usually giving date and time of day, on top of a well-defined and commonly agreed time standard.

7.2 List of requirements

The complete set of requirements is listed in Table 28.

Components	ID	Name	Type	Priority
Supervisor Center	SC_1	System capability	F	M
	SC_2	Layer interoperability	I	M
	SC_3	Open data approach	I	M
	SC_4	Output delay	P	M
Data-Sources Layer	DSL_1	Data gathering	F	M
	DSL_2	Data-source isolation	F	M
	DSL_3	Data pre-validation	F	M
	DSL_4	Data formatting control	F	M
	DSL_5	Data-source forwarding service	F	M
	DSL_6	Source position	F	M
	DSL_7	Source status and data consistency	F	S
	DSL_8	Warning capability	F	S
	DSL_9	Authentication capability	N-F	M
	DSL_10	Source trustworthiness	N-F	M
	DSL_11	Data timestamp	N-F	M
	DSL_12	Source identification	N-F	M
	DSL_13	Source interoperability	I	M
	DSL_14	Elaboration time	P	M
Vehicle Data-Source	VeDS_1	Data type – position and timestamp	F	M
	VeDS_2	Traffic data type	F	M
	VeDS_3	Environmental data type	F	M

	VeDS_4	Data type – position (optional)	F	S
	VeDS_5	Environmental data type (optional)	F	S
	VeDS_6	Data frequency update	P	M
Traffic Station Data-Source	TSDS_1	Data type	F	M
	TSDS_2	Data type (optional)	F	S
	TSDS_3	Data frequency update	P	M
Environmental Station Data-Source	ESDS_1	Data type – environmental parameters	F	M
	ESDS_2	Data type – meteorological parameters	F	M
	ESDS_3	Data type – environmental parameters (optional)	F	S
	ESDS_4	Data frequency update	P	M
User Data-Source	UDS_1	Data type	F	M
	UDS_2	Data type (optional)	F	S
	UDS_3	User identity authentication	N-F	M
	UDS_4	User position	N-F	M
	UDS_5	User identity	N-F	M
	UDS_6	Human machine interface	I	M
3rd Parties Data-Source	3PDS_1	Data type	F	M
	3PDS_2	Data aggregation	F	M
	3PDS_3	3rd parties source authentication and authorization	N-F	M
	3PDS_4	Standard data transfer	I	M
Operator Data-Source	ODS_1	Data type	F	M
	ODS_2	Notification characterization	N-F	M
	ODS_3	Operator role	N-F	M
	ODS_4	Operator authentication	N-F	M
	ODS_5	Human machine interface	I	M
Video data-source	VDS_1	Data type	F	M
	VDS_2	Data type (optional)	F	S
	VDS_3	Notification position	N-F	M
O/D data-source	ODDS_1	Data type – raw generated data	F	M
	ODDS_2	Data type – raw generated data (optional)	F	S
	ODDS_3	Data type – pre-elaborated generated data	F	S
	ODDS_4	Pre-elaboration time interval	P	M
	ODDS_5	Data frequency update	P	M
Meteo data-source	MDS_1	Data type	F	M
	MDS_2	Data type (optional)	F	S
	MDS_3	Data frequency update	P	M
Parking data-source	PDS_1	Data type – generated data	F	M
	PDS_2	Data type – basic information	F	M
	PDS_3	Data frequency update	P	M
Data center layer	DCL_1	System capability	F	M
	DCL_2	Security control	N-F	M
	DCL_3	Performance	P	M
	DCL_4	Flexibility and scalability	P	M
Data center collector	DCC_1	Uniqueness	F	M
	DCC_2	Source and data-source identification	F	M
	DCC_3	Data type recognition	F	M

Database	DCC_4	Database connection	F	M
	DCC_5	Authentication and security	N-F	M
	DCC_6	Data-source authentication management	N-F	M
	DCC_7	Multiple data-source connections support	P	M
	DB_1	GIS capability	F	M
	DB_2	Generated data storing capability	F	M
	DB_3	Intermediate and final elaboration outputs storing capability	F	M
	DB_4	History capability	F	M
	DB_5	Standard logging and reports	F	S
	DB_6	Reliability, security and data incorruptibility capabilities	N-F	M
	DB_7	Data export	N-F	M
	DB_8	Interface	I	M
	DB_9	Performance	P	M
Data center tasks	DCT_1	System capability	F	M
	DCT_2	Output storing capabilities	F	M
	DCT_3	Data accessibility	N-F	M
	DCT_4	Task triggering	N-F	M
	DCT_5	Warning generation management	N-F	S
	DCT_6	Interface mandatory constraints	I	M
	DCT_7	Interface optional extensions	I	C
Pre-elaboration task	PreET_1	Calibration problems discovery	F	M
	PreET_2	Malfunctioning problems discovery	F	S
	PreET_3	Triggering	N-F	M
Elaboration Task	ET_1	Elaboration outputs format	F	M
	ET_2	Traffic elaboration – periodical outputs	F	M
	ET_3	Environmental elaboration - periodical outputs	F	M
	ET_4	On-demand outputs	F	M
	ET_5	Data processing capabilities	N-F	S
	ET_6	Traffic elaboration outputs – spatial resolution	P	M
	ET_7	Environmental elaboration outputs – spatial resolution	P	M
Post-Elaboration Task	PostET_1	Elaboration outputs post-validation	F	M
	PostET_2	On-demand routines management	F	M
	PostET_3	Eco-friendly traffic policies actuation capability	F	M
	PostET_4	Traffic lights center warnings visualization	F	M
	PostET_5	Graphical operator interface	N-F	M
Data center dispatcher	DCD_1	Front-ends request gathering and translation	F	M
	DCD_2	Queries results delivery	F	M
	DCD_3	Architecture hiding	N-F	M
	DCD_4	Multiple front-ends connections support	P	M
Front-ends layer	FEL_1	Output information delivery requests	F	M
	FEL_2	Front-ends isolation	F	M
	FEL_3	Incoming requests pre-validation	F	M

	FEL_4	Front-end requests forwarding service	F	M
	FEL_5	Front-end output information forwarding service	F	M
	FEL_6	Clients request management	N-F	M
	FEL_7	Security management	N-F	M
	FEL_8	Authentication capability	N-F	M
	FEL_9	Client identification	N-F	S
	FEL_10	Client interoperability	I	M
	FEL_11	Scalability	P	M
	FEL_12	Elaboration time	P	M
3rd_parties front-end	3PCF_1	Information type	F	M
	3PCF_2	Standard communication protocols	N-F	M
	3PCF_3	Distribution license	N-F	M
	3PCF_4	Client identification	N-F	M
	3PCF_5	Log records storage	N-F	S
Variable message signs Front-end	VMSF_1	VMSs connection	F	M
	VMSF_2	VMSs messages forwarding service	F	M
	VMSF_3	VMSs maintenance support	F	M
	VMSF_4	Standard communication protocol	N-F	S
	VMSF_5	VMSs information management	N-F	S
Traffic lights center front-end	TLCF_1	Traffic lights dynamic regulation forwarding service	F	M
	TLCF_2	Traffic lights center warnings management	F	M
	TLCF_3	Traffic lights regulation data packet format	F	M
	TLCF_4	Traffic lights centre acknowledgments management	F	S
	TLCF_5	Standard communication protocol	N-F	S
	TLCF_6	Traffic lights information management	N-F	S
Public broadcast channels front-end	PBCF_1	Information type	F	M
	PBCF_2	Information formatting and forwarding service	F	M
	PBCF_3	Broadcast transmission communication technology independency	F	M
	PBCF_4	Standard communication protocols	N-F	M
Public IP channels front-end	PICF_1	Data and information type	F	M
	PICF_2	Data and information formatting and forwarding service	F	M
	PICF_3	Exploitation opportunities	F	M
	PICF_4	Standard communication protocols	N-F	M
	PICF_5	Open data distribution license	N-F	M

Table 28: Requirement list table.

7.3 Supervisor Centre (SC) requirements

This section presents the requirements shared by all the different layers of the architecture.

ID	SC_1
Name	System capability
Description	The Supervisor Centre must be able to (i) gather on a continuous temporal basis data of different nature concerning directly or indirectly with the present traffic and environmental conditions within the city of Bolzano, (ii) elaborate it automatically on a real-time basis (in correspondence of every data collection update), (iii) integrate the actuation inputs provided by the traffic control centre operators and (iv) properly coordinate the traffic control systems as well as the output information that feed the info-mobility channels for the end-users.
Rationale	Overall system target
Type	Functional
Priority	Must

Table 29: Requirement SC_1 (system capability).

ID	SC_2
Name	Layer interoperability
Description	The components within any layer belonging to the SC must interact with the other layers through the layer interfaces by using well defined and documented services.
Rationale	Extensibility. System modularity and scalability
Type	Interface
Priority	Must

Table 30: Requirement SC_2 (layer interoperability).

ID	SC_3
Name	Open data approach
Description	The Supervisor Centre architecture must follow the open data concept for exposing any general results (information, maps, reports, etc.) that is transferable to the end-user clients. The reference definition of open data is the one provided by a recent Italian national law, which states that[15] (i) the data are available under the terms of a license that allows everybody to use it, even for commercial purposes; (ii) the data are accessible through ICT systems and telematic networks, including the possibility for automatic use through specific software components; (iii) the data are published for free or at marginal costs caused by its reproduction and divulgation[16].
Rationale	Standard interoperability
Type	Interface
Priority	Must

Table 31: Requirement SC_3 (open data approach).

7.4 Data-Sources Layer (DSL) requirements

The data-sources layer is composed of several data-source components. Each of them is in charge to (i) gather a well-defined class of data type (i.e. cinematic vehicle data, air pollution data, etc.) and (ii) to put this data at disposal of the upper data center layer.

ID	SC_4
Name	Output delay
Description	The elaboration time of the system should be at maximum 5 minutes.
Rationale	Output freshness
Type	Performance

[15] Decreto-legge 18/10/2012 “Ulteriori misure urgenti per la crescita del Paese”, article 9.
[16] Fees can be accepted only in exceptional cases under the approval of the Digital Italy Agency (Agenzia per l’Italia digitale).

Priority	Must

Table 32: Requirement SC_4 (output delay).

This layer represents the input side for all the data that the Supervisor Center is interested to gather and elaborate. The architecture of this layer as can be seen in Figure 71 is flat, this means that each data-source interacts on the one hand with its own clients (one or more) and on the other hand to the interface of the upper layer called *data center collector*. In addition each data-source is independent and disjointed from all the other, since the types of collected data are by nature specific and are the empirical result of different observations of a target situation . As a result of this structure, the architecture of the layer is both interoperable and extensible in the future, this means that further data-sources can be easily added at a later date. This ensures interoperability between data-sources and the data center collector even when the data sources are produced by different manufactures.

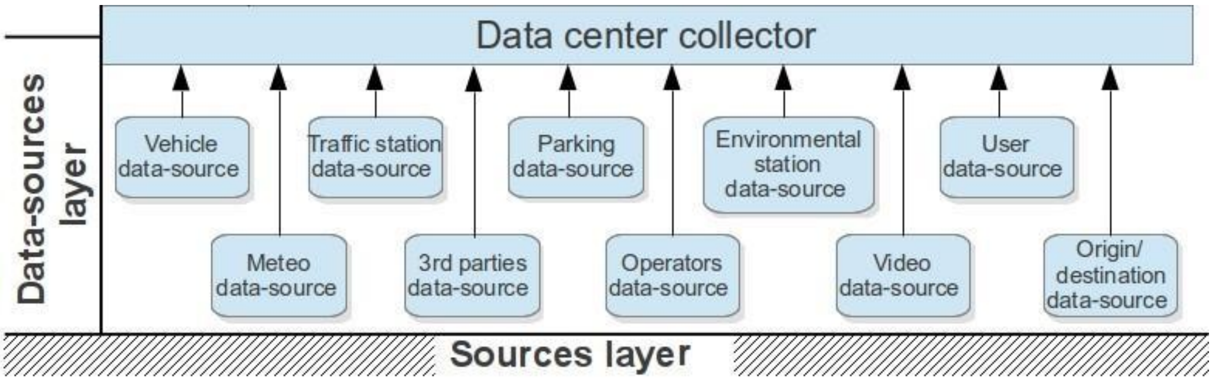


Figure 71: The different data-sources of the Data-Sources Layer.

It is worth noting that the data-sources are not responsible for the proper accuracy of the technological measuring systems which are used by the different sources. These aspects are typically covered by international standards (depending on the nature of the specific measurement), and will be specifically analyzed and taken into consideration within the design and implementation actions.

ID	DSL_1
Name	Data gathering
Description	Any data-source must be able to gather data only from one or more external sources which are in charge to collect corresponding field observations, depending on the monitoring application type.
Rationale	Data sources specificity
Type	Functional
Priority	Must

Table 33: Requirement DSL_1 (data gathering).

ID	DSL_2
Name	Data-source isolation
Description	Any data-source must be an independent entity with respect to the other data-sources and the data center collector.
Rationale	System design

Type	Functional
Priority	Must

Table 34: Requirement DSL_2 (data-source isolation).

ID	DSL_3
Name	Data pre-validation
Description	Any data received as input is dropped unless it follows the defined data type formats.
Rationale	To match the database field definition
Type	Functional
Priority	Must

Table 35: Requirement DSL_3 (data pre-validation).

ID	DSL_4
Name	Data formatting control
Description	Any data-source must drop all received packets of data that are formatted in a different manner as expected.
Rationale	Verification of correct data transmission
Type	Functional
Priority	Must

Table 36: Requirement DSL_4 (data formatting control).

ID	DSL_5
Name	Data-source forwarding service
Description	Any data-source must forward all pre-validated generated data to the data center collector.
Rationale	All pre-validated generated data must be available at an upper layer of the system architecture
Type	Functional
Priority	Must

Table 37: Requirement DSL_5 (data-source forwarding service).

ID	DSL_6
Name	Source position
Description	Any data-source must be able to couple the generated data with the geographic position of the related source.
Rationale	Spatial data characterization
Type	Functional
Priority	Must

Table 38: Requirement DSL_6 (source position).

ID	DSL_7
Name	Source status and data consistency
Description	Whenever possible, the data gathered by the data-source should be marked with the current status of the source.
Rationale	To have details about the current monitoring conditions of the source.
Type	Functional
Priority	Should

Table 39: Requirement DSL_7 (source status and data consistency).

ID	DSL_8
Name	Warning capability
Description	Any data-source should be able to generate a warning in case for example: • the source presents any kind of malfunctioning problems; • the data is inconsistent, not properly formatted and/or not pre-validated; • the client is not authorized.
Rationale	To allow a proper and efficient maintenance of the data collection process.
Type	Functional
Priority	Should

Table 40: Requirement DSL_8 (warning capability).

ID	DSL_9
Name	Authentication capability
Description	Any data-source must be able to authenticate itself with the data center collector.
Rationale	Secure workflow
Type	Non-Functional
Priority	Must

Table 41: Requirement DSL_9 (authentication capability).

ID	DSL_10
Name	Source trustworthiness
Description	Any data-source must have the necessary capabilities in order to guarantee that the generated data are delivered by a trusted source.
Rationale	To prevent spoofing attacks
Type	Non-Functional
Priority	Must

Table 42: Requirement DSL_10 (source trustworthiness).

ID	DSL_11
Name	Data timestamp
Description	Any generated data which is delivered to a data-source must be coupled with the timestamp of the monitoring instant.
Rationale	Generated data and time interval association.
Type	Non-functional
Priority	Must

Table 43: Requirement DSL_11 (data timestamp).

ID	DSL_12
Name	Source identification
Description	Any data-source must send to the data center collector the generated data coupled with the unique identity of the corresponding source.
Rationale	Generated data and source association
Type	Non-functional
Priority	Must

Table 44: Requirement DSL_12 (source identification).

ID	DSL_13
Name	Source interoperability
Description	Any data-source must expose standard software and hardware interfaces, and must use well defined and documented protocols to gather the generated data from the

	related sources.
Rationale	Standard interoperability between sources and data-sources
Type	Interface
Priority	Must

Table 45: Requirement DSL_13 (source interoperability).

ID	DSL_14
Name	Elaboration time
Description	The total amount of time which is needed by the data-source in order to (i) gather the generated data, (ii) perform the pre-validation controls and (iii) forward the pre-validated generated data to the upper layer has to be negligible with respect to the total elaboration time.
Rationale	Data-source performance
Type	Performance
Priority	Must

Table 46: Requirement DSL_14 (elaboration time).

7.4.1 Vehicle Data-Source (VeDS)

The Vehicle Data-Source (VeDS) is in charge to receive the generated data gathered by the mobile probes which can be traffic-related (i.e. the vehicles cinematic parameters) or air pollution-related (i.e. local air pollutant levels). The generated data collected by the experimental fleet of mobile probes is directly controlled by a specific, dedicated vehicle front-end, where first pre-elaboration tasks are possible. The Vehicle Data-Source stays at a higher level, and is in charge to receive the pre-elaborated data from the vehicle front-end. as illustrated in Figure 72. This architecture choice allows a higher degree of flexibility and modularity, since it could open the possibility to receive data collected by existing proprietary AVM systems (e.g. local bus fleets, local taxis, etc.).

ID	VeDS_1
Name	Data type – position and timestamp
Description	Each single generated data record delivered to the vehicle data-source must contain one or more fields related to the correspondent acquisition position of the mobile probe. The position must be characterized in terms of: • coordinates (referred to a standard spatial reference system); • heading (which is the compass direction toward which the mobile probe is moving); • timestamp.
Rationale	System design – specific geospatial constraints for data acquired through mobile monitoring stations
Type	Functional
Priority	Must

Table 47: Requirement VeDS_1 (data type – position and timestamp).

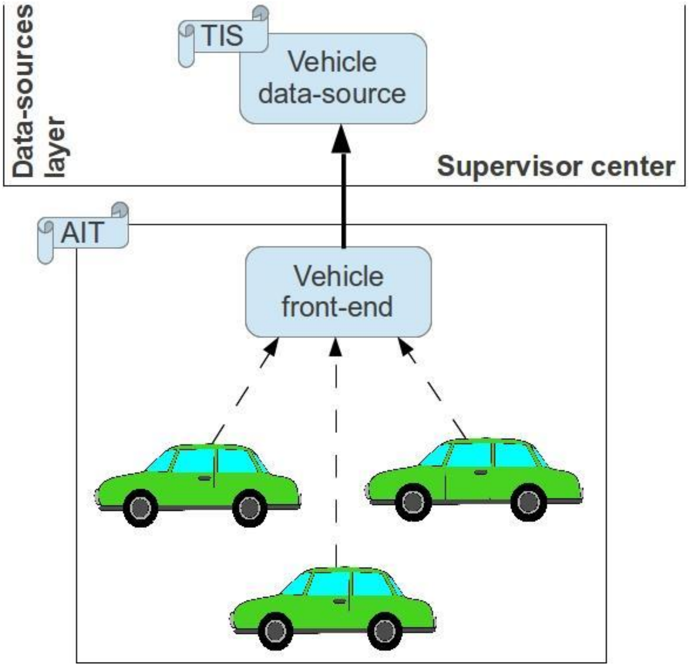


Figure 72: The reference architecture for the Vehicle Data-Source.

ID	VeDS_2
Name	Traffic data type
Description	Each single generated data record delivered to the vehicle data-source must contain one or more fields related to the cinematic status of the mobile probe. The cinematic status must be characterized in terms of: • 1D speed; • 3D acceleration.
Rationale	System design. Basic FCD parameters.
Type	Functional
Priority	Must

Table 48: Requirement VeDS_2 (traffic data type).

ID	VeDS_3
Name	Environmental data type
Description	Each single generated data record delivered to the vehicle data-source must contain one or more fields related to the air pollutant levels monitored by the mobile probe. The air pollutants to be monitored must be: • NO_X; • O_3. Together with these air pollutants it is mandatory to monitor the following meteorological parameters: • air temperature; • humidity;
Rationale	System design. Air pollutants are selected according to (i) specific monitoring needs within the city of Bolzano and (ii) technological constraints.
Type	Functional
Priority	Must

Table 49: Requirement VeDS_3 (environmental data type).

ID	VeDS_4
Name	Data type – position (optional)
Description	Each single generated data record delivered to the vehicle data-source should contain some optional fields related to the accuracy of the acquired position (e.g. quality of the signal acquired by the satellite navigation receiver, number of available satellites, etc.).
Rationale	System design – characterization of geospatial data accuracy
Type	Functional
Priority	Should

Table 50: Requirement VeDS_4 (data type – position (optional)).

ID	VeDS_5
Name	Environmental data type (optional)
Description	Each single generated data record delivered to the vehicle data-source should contain some optional fields related to the air pollutant levels monitored by the mobile probe. The optional air pollutants levels to be monitored must be: • CO; • PM_x; • BC.
Rationale	System design. Further mobile air pollution monitoring capabilities which can complete the mandatory environmental monitoring tasks.
Type	Functional
Priority	Should

Table 51: Requirement VeDS_5 (environmental data type (optional)).

ID	VeDS_6
Name	Data frequency update
Description	The maximum time interval between two consecutive generated data packets delivered to the vehicle data-source must be 5 minutes.
Rationale	Guarantee minimum system performance
Type	Performance
Priority	Must

Table 52: Requirement VeDS_6 (data frequency update).

7.4.2 Traffic Station Data-Source (TSDS)

The Traffic Station Data-Source (TSDS) is in charge to receive the data gathered by the traffic stations installed at fixed points along the monitored roads. The traffic stations reference technology can be invasive (e.g. be based on induction loops) or not (e.g. above-ground radar sensors).

ID	TSDS_1
Name	Data type
Description	Each record of generated data must contain the following fields: ● number of vehicles counted within the window observation; ● speed profile (i.e. all vehicles shall be classified in an aggregated way according to their speed to a speed class of a maximum interval of 10 [km/h], with lower boundary class 0-15 [km/h] and upper boundary class all speeds higher than 70 [km/h]); ● vehicle category (according to the “9+1”- classes Italian standard classification);

	• travel direction.
Rationale	Basic parameters for determining the traffic status according to the reference theories available in the literature.
Type	Functional
Priority	Must

Table 53: Requirement TSDS_6 (data type).

ID	TSDS_2
Name	Data type (optional)
Description	Each record of generated data should contain the following additional fields related to each single vehicular transit: • gap; • headway; • lane (in the case of roads with multiple lanes in the same direction); • sensor occupation time (i.e. the total amount of time in which a vehicle is in the monitoring field of the traffic sensor); • vehicle length.
Rationale	Parameters which can be considered not mandatory but which can increase the level of analysis and elaboration of the generated data.
Type	Functional
Priority	Should

Table 54: Requirement TSDS_2 (data type (optional)).

ID	TSDS_3
Name	Data frequency update
Description	The maximum time interval between two consecutive generated data packets delivered to the traffic station data-source must be 5 minutes.
Rationale	Guarantee minimum system performance
Type	Performance
Priority	Must

Table 55: Requirement TSDS_3 (data frequency update).

7.4.3 Environmental Station Data-Source (ESDS)

The Environmental Station Data-Source (ESDS) is in charge to receive specific data about the air pollutants concentration at a street level. In order to increase the accuracy of the subsequent model elaborations executed at the data center layer, the environmental stations are in charge to acquire and deliver, together with the pollutants, data of meteorological nature too.

ID	ESDS_1
Name	Data type – environmental parameters
Description	Each single generated data record must contain one value of air pollution concentration for each of the following pollutants: • CO • O_3 • NO_X • VOC • $PM_{2.5}$
Rationale	Focus on main air pollutants emitted by traffic which cause the main problems in the

	city of Bolzano. CO is considered as well for joint comparisons with values gathered through the vehicle data-source.
Type	Functional
Priority	Must

Table 56: Requirement ESDS_1 (data type – environmental parameters).

ID	ESDS_2
Name	Data type - meteorological parameters
Description	Each single generated data record must contain one value for each of the following meteorological parameters: ● temperature; ● humidity; ● speed and direction of the wind.
Rationale	To have data that can calibrate the dispersion models at the data center layer.
Type	Functional
Priority	Must

Table 57: Requirement ESDS_2 (data type – meteorological parameters).

ID	ESDS_3
Name	Data type – environmental parameters (optional)
Description	Each record of generated data should contain values about the following air pollutants: ● SO_2 ● NO_2 ● PM_{10} ● BC
Rationale	Air pollutants which can complete the air pollution monitoring tasks (e.g. for NO_2 and PM_{10}) and other air pollutants of minor interests with respect to the needs of the city of Bolzano.
Type	Functional
Priority	Should

Table 58: Requirement ESDS_3 (data type – environmental parameters (optional)).

ID	ESDS_4
Name	Data frequency update
Description	The maximum time interval between two consecutive generated data packets delivered to the environmental station data-source must be 15 minutes.
Rationale	Guarantee minimum system performance
Type	Performance
Priority	Must

Table 59: Requirement ESDS_4 (data frequency update).

7.4.4 User Data-Source (UDS)

The User Data-Source (UDS) together with the Operator Data-Source are the only two input data-sources in which a human interaction plays a fundamental role. It is in charge to gather any information and events that reliable drivers (and travelers in general) are able to notify to the Supervisor Center. The presence of this data-source allows the Supervisor Center to have notifications about both predictable (and unpredictable) events happening in the road network. For example, a policeman on the road can provide to the Supervisor Center fresh and well defined information about a sudden incident or traffic jam. Thanks to this, the Supervisor Center is able to immediately verify (i) the nature of the event and the current status of the involved roads, and as a consequence (ii) the proper activation of the emergency services and recovery plans, which might include the re-distribution of traffic flows on alternative roads.

ID	UDS_1
Name	Data type
Description	Each user notification delivered to the data-source must be associated to one of the following categories: ● accident; ● traffic jam; ● other general event.
Rationale	User notification minimum set of data
Type	Functional
Priority	Must

Table 60: Requirement UDS_1 (data type).

ID	UDS_2
Name	Data type (optional)
Description	Each user notification should be completed with a short description and/or a picture of the notified road situation.
Rationale	User notification optional characterization
Type	Functional
Priority	Should

Table 61: Requirement UDS_2 (data type (optional)).

ID	UDS_3
Name	User identity authentication
Description	The data-source must authenticate the identity of the user when receiving a user notification.
Rationale	Security and data reliability
Type	Non-functional
Priority	Must

Table 62: Requirement UDS_3 (user identity authentication).

ID	UDS_4
Name	User position
Description	Each generated data (i.e. user notification) must contain a field with the current user position.
Rationale	Data-consistency
Type	Non-functional
Priority	Must

Table 63: Requirement UDS_4 (user position).

ID	UDS_5
Name	User identity
Description	Each user notification must be coupled with the authenticated user identity.
Rationale	Security and data reliability

Type	Non-functional
Priority	Must

Table 64: Requirement UDS_5 (user identity).

ID	UDS_6
Name	Human machine interface
Description	The user must interact with the user data-source with a proper user-friendly HMI.
Rationale	Usability requirements
Type	Interface
Priority	Must

Table 65: Requirement UDS_6 (human machine interface).

7.4.5 3rd Parties Data-Source (3PDS)

The 3rd Parties Data-Source (3PDS) represents the input point for gathering generated data coming from other centers (e.g. traffic control and/or information centers, air pollution monitoring centers, etc.) or information sources (e.g. public transport service information).

This data-source, in conjunction with its corresponding front-end at the Front-Ends Layer, allows the Supervisor Center to exchange useful data and/or information with other control authorities, and thus to increase the geographical scope of its monitoring activities, with the possibility to predict and/or to react to specific phenomena which can significantly alter the status of the road network under control (for example, a block in the highway caused by an accident, with traffic flows deviated within the crossing corridors of the city).

ID	3PDS_1
Name	Data type
Description	Each single received data must be linkable to one of the following categories: ● traffic; ● parking; ● air pollution / emissions; ● general events; ● roadworks: ● accidents; ● road conditions; ● public transport; ● others.
Rationale	Characterization of possible data types received by 3rd parties sources.
Type	Functional
Priority	Must

Table 66: Requirement 3PDS_1 (data type).

ID	3PDS_2
Name	Data aggregation
Description	The data-source must be able to properly aggregate the data depending on (i) reference category and (ii) time delivery modalities defined by the 3rd parties sources.
Rationale	Efficient aggregation operations of the data flows for an efficient forwarding service to the upper level.
Type	Functional

Priority	Must

Table 67: Requirement 3PDS_2 (data aggregation).

ID	3PDS_3
Name	3rd parties source authentication and authorization
Description	The data-source must recognize and authorize each external 3rd parties source.
Rationale	Security
Type	Non-functional
Priority	Must

Table 68: Requirement 3PDS_3 (3rd parties source authentication and authorization).

ID	3PDS_4
Name	Standard data transfer
Description	The data provided by each 3rd parties source must be exposed with a standard data exchange protocol (e.g. DATEX II, SIRI, VDV, etc.).
Rationale	Standard interoperability
Type	Interface
Priority	Must

Table 69: Requirement 3PDS_4 (standard data transfer).

7.4.6 Operators Data-Source (ODS)

The Operator Data-Source (ODS) allows the Supervisor Center operators to introduce additional information within the system.

ID	ODS_1
Name	Data type
Description	Each operator notification must be associated to one of the following categories: • roadworks; • general city events.
Rationale	Characterization of possible data types that can be introduced by authorized operators.
Type	Functional
Priority	Must

Table 70: Requirement ODS_1 (data type).

ID	ODS_2
Name	Notification characterization
Description	Each notification must have a short reference description, be spatially characterized and contain information about the temporal scope of the notification.
Rationale	System design
Type	Non-functional
Priority	Must

Table 71: Requirement ODS_2 (notification characterization).

ID	ODS_3
Name	Operator role
Description	The additional information can be introduced in the data-source only by one or more operators having specific privileges.

Rationale	Security
Type	Non-Functional
Priority	Must

Table 72: Requirement ODS_3 (operator role).

ID	ODS_4
Name	Operator authentication
Description	The operator data-source must be able to authenticate the operator.
Rationale	Security
Type	Non-Functional
Priority	Must

Table 73: Requirement ODS_3 (operator authentication).

ID	ODS_5
Name	Human machine interface
Description	The operator must interact with the operator data-source with a proper user-friendly HMI.
Rationale	Usability requirements
Type	Interface
Priority	Must

Table 74: Requirement ODS_4 (human machine interface).

7.4.7 Video Data-Source (VDS)

The Video Data-Source (VDS) interacts with the video monitoring system which is already available at the Supervisor Centre. This data-source is in charge to collect the automatic notifications that this system is capable to elaborate through the proper video processing algorithms which are continuously applied to the acquired video signals. For simplicity sake, in this section it has been decided to not consider the monitoring tasks performed by the operators through a visual analysis the video signals displayed on the video wall of the control room. This activity can be considered out of the scope of the INTEGREEN project.

ID	VDS_1
Name	Data type
Description	Each notification must be associated to one of the following categories: ● accident; ● traffic jam; ● other events.
Rationale	Characterization of possible data types that can be received by the video source.
Type	Functional
Priority	Must

Table 75: Requirement VDS_1 (data type).

ID	VDS_2
Name	Data type (optional)
Description	Each notification associated to the category “other events” should be associated with the following further sub-categories: ● other traffic-related safety alarms (for example, stationary vehicle at the road side);

	• other environmental-related safety alarms (for example, an anomalous emissions peak generated by one or more vehicles); • other unclassifiable events.
Rationale	Video notification optional characterization
Type	Functional
Priority	Should

Table 76: Requirement VDS_2 (data type (optional)).

ID	VDS_3
Name	Notification position
Description	Each generated data (i.e. video notification) must contain a field with the corresponding position.
Rationale	Data-consistency
Type	Non-functional
Priority	Must

Table 77: Requirement VDS_3 (notification position).

7.4.8 O/D Data-Source (ODDS)

The Origin/Destination (O/D) Data-Source (ODDS) is in charge to gather the data coming from the origin/destination source, which is a monitoring system based on the ANPR technology that aims to identify the passages of vehicles at specific points through the automatic recognition of their number plate and to let them match them at different locations in order to statistically quantify on a real-time basis (i) the traffic flows on a specific O/D couple and (ii) the correspondent travel times.

The O/D source is characterized by an architecture which is similar to the one introduced for the vehicle source, where monitoring stations installed on the roads are connected to a central front-end where data are first collected and pre-elaborated. In this case, the computations performed at this level cover points (i) and (ii). The O/D data source is interested in receiving both the generated data collected by the monitoring stations as well as the pre-elaboration outputs.

ID	ODDS_1
Name	Data type – raw generated data
Description	The O/D data-source must receive the raw generated data collected by a specific monitoring station of the O/D source, located at a specific point of the road network, i.e.: • the total number of vehicles recognized within the window observation; • a vehicle identifier which is anonymously associated to the number plate of each passing vehicle.
Rationale	Minimum set of raw generated data to be collected by the O/D source.
Type	Functional
Priority	Must

Table 78: Requirement ODDS_1 (data type – raw generated data).

ID	ODDS_2
Name	Data type – raw generated data (optional)
Description	The O/D data-source should optionally receive, as integration to the raw generated data collected by a specific monitoring station of the O/D source, a field which associates to each identified vehicle the corresponding vehicle category, based on the Italian 9+1 standard.
Rationale	Optional set of additional raw generated data to be collected by the O/D source.
Type	Functional
Priority	Should

Table 79: Requirement ODDS_2 (data type – raw generated data (optional)).

ID	ODDS_3
Name	Data type – pre-elaborated generated data
Description	The O/D data-source should additionally receive the pre-elaborated generated data computed by the O/D front-end, i.e. for each O/D couple: • the total number of vehicles that have transited trough these interest points; • a set of statistics concerning travel times.
Rationale	Optional set of additional pre-elaborated generated data to be collected by the O/D source.
Type	Functional
Priority	Should

Table 80: Requirement ODDS_3 (data type – pre-elaborated generated data).

ID	ODDS_4
Name	Pre-elaboration time interval
Description	The maximum time interval to be considered for the computation of pre-elaborated generated data must be defined according to the typical number of matches in the time unit for a specific O/D couple.
Rationale	The threshold is based on typical travel times in the city of Bolzano, and has to consider the ability for drivers to complete a specific O/D travel.
Type	Performance
Priority	Must

Table 81: Requirement ODDS_4 (pre-elaboration time interval).

ID	ODDS_5
Name	Data frequency update
Description	The maximum time interval between two consecutive generated data packets delivered to the O/D data-source must be 5 minutes.
Rationale	Guarantee minimum system performance
Type	Performance
Priority	Must

Table 82: Requirement ODDS_5 (data frequency update).

7.4.9 Meteo Data-Source (MDS)

The Meteo Data-Source (MDS) represents the reference aggregation point for all the weather information gathered by the meteo stations distributed in the area of the city of Bolzano. This information are strongly demanded by the integrated elaborations performed at the data center layer (i.e., the need to elaborate both the traffic and air pollutions trends).

ID	MDS_1
Name	Data type
Description	Each single generated data record must contain one value for each of the following meteorological parameters: ● temperature; ● humidity; ● wind speed and direction; ● type, intensity and quantity of precipitation;
Rationale	Minimum set of generated data to be collected by the meteo source.
Type	Functional
Priority	Must

Table 83: Requirement MDS_1 (data type).

ID	MDS_2
Name	Data type (optional)
Description	Each record of generated data should contain the following additional fields with values covering the current state of: ● environmental pressure; ● dew point; ● solar irradiation.
Rationale	Optional set of additional generated data to be collected by the meteo source.
Type	Functional
Priority	Should

Table 84: Requirement MDS_2 (data type (optional)).

ID	MDS_3
Name	Data frequency update
Description	The maximum time interval between two consecutive generated data packets delivered to the meteo data-source must be 15 minutes.
Rationale	Guarantee minimum system performance which is compatible with the one requested to the environmental stations data-source
Type	Performance
Priority	Must

Table 85: Requirement MDS_3 (data frequency update).

7.4.10 Parking Data-Source (PDS)

The Parking Data-Source (PDS) is in charge to gather data regarding the current occupancy status of the main parking areas distributed in the city of Bolzano. By gathering the real-time number of free/occupied spots, the Supervisor Center has the chance to better distribute urban traffic by properly routing vehicular flows to the nearest and free parking areas.

ID	PDS_1
Name	Data type – generated data
Description	Each record of generated data must contain the number of free slots of a specific parking area.
Rationale	Minimum set of generated data to be collected by the parking source.
Type	Functional
Priority	Must

Table 86: Requirement PDS_1 (data type – generated data).

ID	PDS_2
Name	Data type – basic information
Description	The parking data-source must have basic information about the number of available slots that each controlled parking area can manage.
Rationale	Mandatory information in order to evaluate the current level of occupancy of the parking areas.
Type	Functional
Priority	Must

Table 87: Requirement PDS_2 (data type – basic information).

ID	PDS_3
Name	Data frequency update
Description	The maximum time interval between two consecutive generated data packets delivered to the parking data-source must be 5 minutes.
Rationale	Guarantee minimum system performance which is compatible with the one requested to the traffic stations data-source.
Type	Performance
Priority	Must

Table 88: Requirement PDS_2 (data frequency update).

7.5 Data Center Layer (DCL) requirements

The data center layer is the core engine of the Supervisor Center. It plays a twofold role, since on the one hand it is in charge to apply the proper elaboration activities/routines onto the coming data gathered by the several data-sources connected through the data center collector, while on the other hand it is in charge to make available both the validated generated data and the elaborated ones to the several front-ends through the data center dispatcher. In this latter case, further elaborations might be necessary in order to respond to the coming queries.

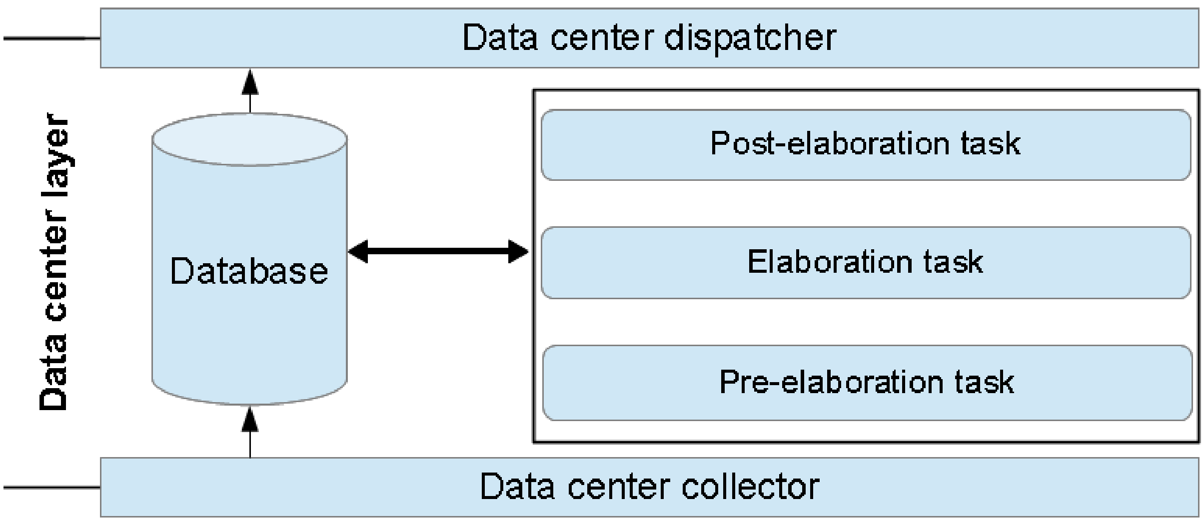


Figure 73: The building blocks of the Data Center Layer.

ID	DCL_1
Name	System capability
Description	The Data Center Layer (DCL) must be able to: • collect and store the generated data as well as the elaboration outputs and, where necessary, all relevant intermediate elaboration products; • coordinate the automatic data elaboration routines; • make validated data and elaboration outputs properly accessible at an upper layer.
Rationale	Overall Data Center Layer target
Type	Functional
Priority	Must

Table 89: Requirement DCL_1 (system capability).

ID	DCL_2
Name	Security control
Description	The Data Center Layer must present sufficient protection measures in order to prevent any kind of external attacks and thus maximize the overall security. In case of intrusion or other system violation, the Data Center Layer must be able to monitor and provide notifications to the authorized staff.
Rationale	Security of the system
Type	Non-functional
Priority	Must

Table 90: Requirement DCL_2 (security control).

ID	DCL_3
Name	Performance
Description	The Data Center Layer must be able to process all the received data in a “real time” mode, so that requirement SC_4 is properly satisfied.
Rationale	System design
Type	Performance
Priority	Must

Table 91: Requirement DCL_3 (performance).

ID	DCL_4
Name	Flexibility and scalability
Description	The Data Center Layer must be designed in a way such that a high degree of flexibility and scalability for matching present and future needs is possible.
Rationale	To facilitate future system integration and expansion.
Type	Performance
Priority	Must

Table 92: Requirement DCL_4 (flexibility and scalability).

7.5.1 Data Center Collector (DCC)

In the Supervisor Centre architecture the data center collector is in charge to provide a single and unique point with whom all the data-sources must interact in order to deliver the data which they gathered from all their respective sources. In addition to this, it has the role to interact with the database and to store the data in an appropriate manner, such that (i) subsequent elaborations are possible and (ii) a clear reference to the correspondent data-source is always available, in order at a later date to trace the behavior of both data-sources and correspondent sources.

ID	DCCL_1
Name	Uniqueness
Description	The Data Center Collector must be the unique collection point for all data-sources.
Rationale	System design
Type	Functional
Priority	Must

Table 93: Requirement DCC_1 (uniqueness).

ID	DCCL_2
Name	Source and data-source identification
Description	The Data Center Collector must be able to identify the data-source which is providing the data and, based on requirement DSL_12, the specific source which has gathered it.
Rationale	To guarantee proper system maintenance and control activities
Type	Functional
Priority	Must

Table 94: Requirement DCC_2 (source and data-source identification).

ID	DCCL_3
Name	Data type recognition
Description	The Data Center Collector must be able to identify the nature of the received data (i.e., environmental- or traffic related).
Rationale	To optimize data storage and elaboration
Type	Functional
Priority	Must

Table 95: Requirement DCC_3 (data type recognition).

ID	DCCL_4
Name	Database connection
Description	The Data Center Collector must be able to connect to the database and to store data on the base of its specifications.
Rationale	System design
Type	Functional
Priority	Must

Table 96: Requirement DCC_4 (database connection).

ID	DCCL_5
Name	Authentication and security
Description	The Data Center Collector must authenticate itself to the database and execute the storing actions in a secure way
Rationale	Database authenticated and secure access
Type	Non-functional
Priority	Must

Table 97: Requirement DCC_5 (authentication and security).

ID	DCCL_6
Name	Data-source authentication management

Description	The Data Center Collector must properly manage the authentication procedure with the underlying data-sources, in synergy with requirement DSL_9.
Rationale	Secure data collection
Type	Non-functional
Priority	Must

Table 98: Requirement DCC_6 (data-source authentication management).

ID	DCCL_7
Name	Multiple data-source connections support
Description	The Data Center Collector must have the capability to properly open and manage multiple connections with the underlying data sources. The presence of other open connections must be as much as transparent for a data-source, and not produce significant delays in the generated data transfer.
Rationale	System design
Type	Performance
Priority	Must

Table 99: Requirement DCC_7 (multiple data-source connections support).

7.5.2 Data Base (DB)

The Database (DB) is the core of the Supervisor Center, where all the information, data, output results gathered and elaborated at this layer are stored.

ID	DB_1
Name	GIS capability
Description	The Database must be spatial, i.e. able to store and handle geo-referenced data organized with complex data models
Rationale	Spatial dimension is a fundamental element in the elaboration chain
Type	Functional
Priority	Must

Table 100: Requirement DB_1 (GIS capabilty).

ID	DB_2
Name	Generated data storing capability
Description	The Database must be able to store all data received by the Data Center Collector.
Rationale	System design
Type	Functional
Priority	Must

Table 101: Requirement DB_2 (generating data storing capability).

ID	DB_3
Name	Intermediate and final elaboration outputs storing capability
Description	The Database must be able to store all elaboration outputs, including where relevant the intermediate ones as well.
Rationale	System design
Type	Functional
Priority	Must

Table 102: Requirement DB_3 (intermediate and final elaboration outputs storing capability).

ID	DB_4
Name	History capability
Description	The Database must be able to efficiently store and manage the data and outputs history.
Rationale	Historical data play a fundamental role in the elaboration processing.
Type	Functional
Priority	Must

Table 103: Requirement DB_4 (history capability).

ID	DB_5
Name	Standard logging and reports
Description	The Database should be able to log transactions and to generate standard reports.
Rationale	Database transactions monitoring and evaluation
Type	Functional
Priority	Should

Table 104: Requirement DB_5 (standard logging and reports).

ID	DB_6
Name	Reliability, security and data incorruptibility capabilities
Description	The Database must be able to guarantee that storing and access activities are performed in a reliable and secure way, and that data are not corrupted over time..
Rationale	Basic system reliability needs
Type	Non-functional
Priority	Must

Table 105: Requirement DB_6 (reliability, security and data incorruptibility capabilities).

ID	DB_7
Name	Data export
Description	It must be able to dump a part or even the entire set of data stored in the Database
Rationale	Off-line data elaboration needs
Type	Non-functional
Priority	Must

Table 106: Requirement DB_7 (data export).

ID	DB_8
Name	Interfaces
Description	The Database must provide an external access via protocols and language bindings to the following components: • Data Center Collector; • Elaboration Tasks; • Data Center Dispatcher.
Rationale	System design
Type	Interface
Priority	Must

Table 107: Requirement DB_8 (interfaces).

ID	DB_9
Name	Performance
Description	The time needed by the Database in order to answer to entering queries must be negligible if compared to the total system elaboration time (ref. requirement SC_4)

	and must not be significantly influenced by: ● the number of parallel accesses opened by the single interface; ● the number of parallel accesses opened across several interfaces; ● the whole amount of different data.
Rationale	System performance demand
Type	Performance
Priority	Must

Table 108: Requirement DB_9 (performance).

7.5.3 Data Center Tasks (DCT)

The Data Center Tasks (DCT) can be simply seen as a container of several routines. Most of the tasks are in charge of performing an elaboration onto the data stored in the database and to store the results back in the database. A small set of tasks, carried out with the manual coordination of the operator at the Supervisor Centre, focus on the actuation of specific strategies onto the traffic systems and info-mobility channels.

The routines can be grouped into two main categories according to the way that they are triggered to be executed. On the one hand there are those, called *periodically routines*, which are executed at predefined time frames while on the other hand there are the *on-demand tasks* which do not have a predefined schedule but are triggered to be executed based on specific events happened instead. A further distinction can be made with respect to the nature of the single routines: a first set of routines is in fact destined to the calculation of *the current traffic conditions*, while a second set of routines target the *environmental impact caused by urban traffic*.

ID	DCT_1
Name	System capability
Description	The Data Center Tasks must: • elaborate the data stored in the database in order to calculate the current (or historical) traffic and air pollution conditions within the monitored area of the city; • be able to perform the actuation strategies defined and inserted within the system by the operators.
Rationale	Overall data center tasks target
Type	Functional
Priority	Must

Table 109: Requirement DCT_1 (system capability).

ID	DCT_2
Name	Outputs storing capabilities
Description	Any Data Center Task must be able to store its generated outputs in the database.
Rationale	History generation and post-usability of the generated outputs
Type	Functional
Priority	Must

Table 110: Requirement DCT_2 (outputs storing capabilities).

ID	DCT_3
Name	Data accessibility
Description	Any task must be able to access all the kind of data that are needed to carry out its elaboration task.
Rationale	Basic needs for data elaboration
Type	Non-functional
Priority	Must

Table 111: Requirement DCT_3 (data accessibility).

ID	DCT_4
Name	Task triggering
Description	Depending on the purpose, the execution of each task must be triggered: ● **periodically**, in the case the objective is to automatically produce an update of the previously calculated outputs (i.e. current traffic / environmental conditions); ● **on-demand**, in the case the objective is to manually activate a particular elaboration on the data or an actuation on the traffic control systems.
Rationale	System design
Type	Non-Functional
Priority	Must

Table 112: Requirement DCT_4 (task triggering).

ID	DCT_5
Name	Warning generation management
Description	Any task should be able to fire a warning in case of need to the Database as well as to the Supervisor Centre operators.
Rationale	Guarantees the error traceability and handling
Type	Non-Functional
Priority	Should

Table 113: Requirement DCT_5 (warning generation management).

ID	DCT_6
Name	Interface mandatory constraints
Description	The Data Center Tasks must interact only with the Database. No interaction must be possible with the other components of the system architecture.
Rationale	Security requirements
Type	Interface
Priority	Must

Table 114: Requirement DCT_6 (interface mandatory constraints).

ID	DCT_7
Name	Interface optional extensions
Description	The Data Center Tasks could optionally interact, in a future system elaboration expansion, with trusted elaboration tools i.e. in the case of traffic elaborations, with a traffic simulation tool.
Rationale	Elaboration outputs enrichment opportunity
Type	Interface
Priority	Could

Table 115: Requirement DCT_7 (interface optional extensions).

Pre-Elaboration Task (PreET)

The Pre-Elaboration Task (PreET) represents the first step of the elaboration pipeline performed in the Data Center Layer. The main target here is to perform a data validation according to the physical client source specifications, e.g., the pre-elaboration task for the meteorological data has the abilities to understand when a data acquired by a physical sensor is no longer reliable due to a stronger derivative with respect to the factory defaults.

ID	PreET_1
Name	Calibration problems discovery
Description	The Pre-Elaboration Task must pre-process all the data stored in the Database in order to find out outlayers and unreliable data, e.g. acquired by a data source which is out of calibration. This data must be properly marked and must be excluded from the elaboration chain. A warning must be fired, following the principle of requirement DCT_5.
Rationale	To guarantee that the elaboration outputs are not erroneously biased and are as much as possible representative of the real situation.
Type	Functional
Priority	Must

Table 116: Requirement PreET_1 (calibration problems discovery).

ID	PreET_2
Name	Malfunctioning problems discovery
Description	The Pre-Elaboration Task should be able to analyze the sources status and to discover any malfunction occurrence in the source. The malfunctioning problem should be signaled through a proper warning, following the principle of requirement DCT_5.
Rationale	To guarantee a proper maintenance of the sources.
Type	Functional
Priority	Should

Table 117: Requirement PreET_2 (malfunctioning problems discovery).

ID	PreET_3
Name	Triggering
Description	The Pre-Elaboration Task must be triggered periodically, as soon as there is a data record update in the database coming from the Data Center Collector.
Rationale	System design
Type	Non-functional
Priority	Must

Table 118: Requirement PreET_3 (triggering).

Elaboration Task (ET)

The Elaboration Task (ET) is the core step of the elaboration pipeline, which has the role of running all the elaboration models onto the gathered data.

ID	ET_1
Name	Elaboration outputs format
Description	The Elaboration Task must produce geo-spatial outputs.
Rationale	The outputs must be available in both textual / numerical form and map rendering
Type	Functional

Priority	Must

Table 119: Requirement ET_1 (elaboration outputs format).

ID	ET_2
Name	Traffic elaboration – periodical outputs
Description	On a periodical basis, the traffic-related routines must produce as final output an update for: • a four-class classification of the current traffic conditions of the monitored road network (“low”, “medium”, “high”, “congested”); • a short-term prediction (i.e. over one hour) of the traffic conditions, to be elaborated as in the point before, based on a comparison between current and historical data.
Rationale	Elaboration tasks must produce a fresh output which is easily understandable by a human being and which can be easily used at the clients layer. Predictions are required in order to drive an efficient trip planning behavior change in the final users.
Type	Functional
Priority	Must

Table 120: Requirement ET_2 (traffic elaboration – periodical outputs).

ID	ET_3
Name	Environmental elaboration – periodical outputs
Description	On a periodical basis, the environmental-related routines must produce as final output an update for: • an emission map for: ❖ air pollutants (NO_x, CO, PM_{10}); ❖ fuel consumption; ❖ greenhouse gases (CO_2); • a dispersion map, which presents the traffic-induced air pollutants concentration over the city.
Rationale	Elaboration tasks must produce a fresh output which is easily understandable by a human being and which can be easily used at the clients layer.
Type	Functional
Priority	Must

Table 121: Requirement ET_3 (environmental elaboration – periodical outputs).

ID	ET_4
Name	On-demand outputs
Description	The Elaboration Task must have routines to be started on-demand which return statistics on the past traffic/ environmental conditions over the monitored routes (e.g. the average daily traffic profile over a route section, the average daily emission profile over a route section, etc.).
Rationale	Historic data contain a lot of information which can be efficiently exploited.
Type	Functional
Priority	Must

Table 122: Requirement ET_4 (on-demand outputs).

ID	ET_5
Name	Data processing capabilities
Description	The Elaboration Task should be enriched by available algorithms, libraries, software tools in order to process the pre-validated data as expected and in the given time constraints.
Rationale	Data processing simplification

Type	Non-Functional
Priority	Should

Table 123: Requirement ET_5 (data processing capabilities).

ID	ET_6
Name	Traffic elaboration outputs – spatial resolution
Description	The spatial resolution of traffic elaboration outputs must be at maximum 100 [m], i.e. a classification label must be assigned to each elementary road section which must have this value as maximum extension.
Rationale	System design
Type	Performance
Priority	Must

Table 124: Requirement ET_6 (traffic data elaboration outputs – spatial resolution).

ID	ET_7
Name	Environmental elaboration outputs – spatial resolution
Description	The spatial resolution of environmental elaboration outputs must be at maximum: • 100 [m] for the emission map, since it is primarily calculated on the base of traffic data for each elementary road section; • 100 [m] for the dispersion map, which is intended as maximum horizontal spacing for each elementary cell of the map grid.
Rationale	System design
Type	Performance
Priority	Must

Table 125: Requirement ET_7 (environmental data elaboration outputs – spatial resolution).

Post-Elaboration Task (PostET)

The Post-Elaboration Task (PostET) is in charge of performing operations on the output results produced in the elaboration task. This task is directly managed by an authorized operator who is in charge not only to evaluate and post-validate the generated outputs, but also to define and implement eco-friendly traffic actuation activities (e.g. modified traffic lights cycles).

ID	PostET_1
Name	Elaboration outputs post-validation
Description	The periodic elaboration outputs must be presented at the operator and, where necessary, receive a post-validation by an authorized operator of the Supervisor Centre before they are published to the front-ends layer.
Rationale	Elaboration outputs must be checked by a human being before to be used in info-mobility applications.
Type	Functional
Priority	Must

Table 126: Requirement PostET_1 (elaboration outputs post-validation).

ID	PostET_2
Name	On-demand routines management
Description	The operator must be able to start the on-demand routines described in requirement ET_6.
Rationale	The operator must be able to analyze the current situation in detail and to have a

	decision support that allows him/her to react accordingly in the short- and long-term.
Type	Functional
Priority	Must

Table 127: Requirement PostET_2 (on-demand routines management).

ID	PostET_3
Name	Eco-friendly traffic policies actuation capability
Description	The operator must have the possibility to dynamically and remotely actuate specific eco-friendly traffic policies, which can include, among the others: • a change of the cycle of one or more traffic lights; • a change in the variable speed limits; • a change in the circulation permissions over specific routes; • a change in the travel choices of mobility participants (e.g. incentives to take specific routes within the city, or to choose alternatives in combination with other travel means); In particular, the operator must have the possibility: • to define one or more modifications in the cycle of one or more traffic lights and to send this new regulations to the traffic lights control system through its front-end; • to insert the textual messages to be displayed over the VMSs; • to introduce manual messages and recommendations to be delivered to the traveler over the public broadcast- and IP channels front-ends; • to introduce manual warnings to be delivered to other traffic control centers through the 3rd parties front-end.
Rationale	The operator must have the instruments to dynamically implement the eco-friendly traffic policies that he/she wants to actuate.
Type	Functional
Priority	Must

Table 128: Requirement PostET_3 (eco-friendly traffic policies actuation capability).

ID	PostET_4
Name	Traffic lights center warnings visualization
Description	The operator must be able to receive and visualize eventual warnings coming from the traffic lights centre concerning the application of a specific dynamic regulation.
Rationale	The operator must be in the condition to check if a specific traffic light cycle regulation he/she decided to apply was actuated as expected
Type	Functional
Priority	Must

Table 129: Requirement PostET_4 (traffic lights center warnings visualization).

ID	PostET_5
Name	Graphical operator interface
Description	The operator must avail of a user-friendly graphical interface in order to easily perform the operations described in the previous requirements.
Rationale	System design
Type	Non-functional
Priority	Must

Table 130: Requirement PostET_5 (graphical operator interface).

7.5.4 Data Center Dispatcher (DCD)

The Data Center Dispatcher (DCD) to some extent can be seen as the opposite of the Data Center Collector. As the latter, it is an unique and single point in charge of creating an unique interface between the Database and the Front-End Layer. Its own task is to (i) gather all the requests coming from any front-end and translate them into queries for the database, and (ii) to deliver the queries results provided by the database to the front-end that has made the request.

ID	DCD_1
Name	Front-ends request gathering and translation
Description	The Data Center Dispatcher must properly gather the requests coming from the front-ends and translate them into queries for the Database
Rationale	System design
Type	Functional
Priority	Must

Table 131: Requirement DCD_1 (front-ends request gathering and translation).

ID	DCD_2
Name	Queries results delivery
Description	The Data Center Dispatcher must forward the queries results generated by the Database to the front-end that has generated the request.
Rationale	System design
Type	Functional
Priority	Must

Table 132: Requirement DCD_2 (queries results delivery).

ID	DCD_3
Name	Architecture hiding
Description	The Data Center Dispatcher must hide the complexity of the architecture of the Data center layer, playing as the single point of access to the validated information base.
Rationale	System design
Type	Non-Functional
Priority	Must

Table 133: Requirement DCD_3 (architecture hiding).

ID	DCD_4
Name	Multiple front-ends connections support
Description	The Data Center Dispatcher must have the capability to properly open and manage multiple connections with the overlying front-ends. The presence of other open connections must be as much as transparent for a front-end, and not produce significant delays in the generated data transfer.
Rationale	System design
Type	Performance
Priority	Must

Table 134: Requirement DCD_4 (multiple front-ends connections support).

7.6 Front-Ends Layer (DCL) requirements

The Front-Ends Layer (FEL) has the role of presenting the validated information available in the Supervisor Center to the external client entities. In particular any front-end is in charge of making those information accessible to its own specific clients. As a result, any request elaborated by these latter clients will pass through one or more front-ends. By doing this, very different clients are able to interact with the Supervisor Center over a variety of communication networks by using their preferred data transport protocol implemented by the specific front-end. Given these premises, other and different modalities or approaches to interact with the Supervisor Centre are neither considered nor available.

Please note that the front-ends can be seen as an opposite component with respect to the data-source, since here the aim is to deliver validated information to a client rather than collect raw generated data from a source. Many of the requirements defined at the data-source layer can be here taken in consideration, adapted as a function of this different role.

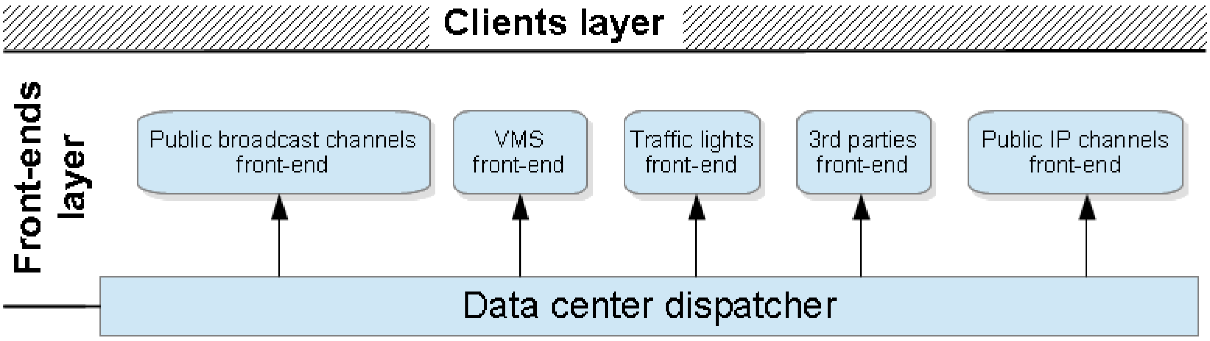


Figure 74: The building blocks of the Front-End Layer.

ID	FEL_1
Name	Output information delivery requests
Description	Any front-end must be able to be contacted by one or more specific and supported external clients wanting to have access to certain validated information available at the Data Center Layer.
Rationale	Front-ends specificity
Type	Functional
Priority	Must

Table 135: Requirement FEL_1 (output information delivery requests).

ID	FEL_2
Name	Front-ends isolation
Description	Any front-end must be an independent entity with respect to the other front-ends and the Data Center Dispatcher.
Rationale	System design
Type	Functional
Priority	Must

Table 136: Requirement FEL_2 (front-ends isolation).

ID	FEL_3
Name	Incoming requests pre-validation
Description	Any front-end must drop all received requests that are formatted in a different manner as expected.

Rationale	To match the data transport protocols specifications
Type	Functional
Priority	Must

Table 137: Requirement FEL_3 (incoming requests pre-validation).

ID	FEL_4
Name	Front-end requests forwarding service
Description	Any front-end must forward to the Database only those requests concerning data that it has the role to access.
Rationale	Only a limited set of requests are possible for a client and its correspondent front-end.
Type	Functional
Priority	Must

Table 138: Requirement FEL_4 (front-end requests forwarding service).

ID	FEL_5
Name	Front-end output information forwarding service
Description	Any front-end must forward to the end-user client the reply to its request which is generated by the Database and received through the Data Center Dispatcher.
Rationale	System design
Type	Functional
Priority	Must

Table 139: Requirement FEL_5 (front-end output information forwarding service).

ID	FEL_6
Name	Clients requests management
Description	Any front-end must process the different clients requests in the same manner, i.e. through all the same processing steps, and independently from the client identity.
Rationale	To guarantee that all clients receive the same level of service.
Type	Non-functional
Priority	Must

Table 140: Requirement FEL_6 (clients requests management).

ID	FEL_7
Name	Security management
Description	Any front-end must have sufficient capabilities to prevent any improper use of the resources and any malicious attacks (e.g. denial-of-service).
Rationale	To guarantee a high level of security in the data delivery process.
Type	Non-functional
Priority	Must

Table 141: Requirement FEL_7 (security management).

ID	FEL_8
Name	Authentication capability
Description	Any front-end must be able to authenticate itself with the Data Center Dispatcher
Rationale	Secure workflow
Type	Non-functional
Priority	Must

Table 142: Requirement FEL_8 (authentication capability).

ID	FEL_9
Name	Client identification
Description	Any front-end should be identified by the Data Center Dispatcher by coupling the client's request with its own identifier.
Rationale	Creation of an association between client's request and correspondent front-end.
Type	Non-functional
Priority	Should

Table 143: Requirement FEL_9 (client identification).

ID	FEL_10
Name	Client interoperability
Description	Any front-end must expose a standard interface and use well defined and documented protocols to interact with the end-user clients.
Rationale	Standard interoperability between front-ends and end-users clients
Type	Interface
Priority	Must

Table 144: Requirement FEL_10 (client interoperability).

ID	FEL_11
Name	Scalability
Description	Any front-end must be implemented in such a way so that it can be easily scaled as a function of the amount of incoming requests.
Rationale	Easy system exploitation
Type	Performance
Priority	Must

Table 145: Requirement FEL_10 (scalability).

ID	FEL_12
Name	Elaboration time
Description	Assuming that the connection between front-end and client is sufficiently stable and broadband, the total amount of time which is needed by the system to reply to a request of an end-user client must be compliant with the user's expectation, i.e. at maximum 5 [s].
Rationale	Output information service delivery basic performance
Type	Performance
Priority	Must

Table 146: Requirement FEL_12 (elaboration time).

7.6.1 3rd Parties Center Front-End (3PCF)

The 3rd Parties Center Front-End (3PCF) is in charge of exchanging relevant traffic-related information to others traffic centers (e.g. traffic management centers, traffic information centers, etc.). The front-end is the complementary part of the 3rd parties data-source. As a matter of fact, this front-end has the ability to interact and exchange the data with a 3rd parties data-source of another equivalent traffic center (Figure 75), which represents in this scenario, the authorized clients of the 3rd Parties Center Front-End.

As a result of the standard interfaces used for the bi-directional data exchange, both the front-end and the data-source are able to interact using the same communication language with different control centers without any additional or specific implementation needs.

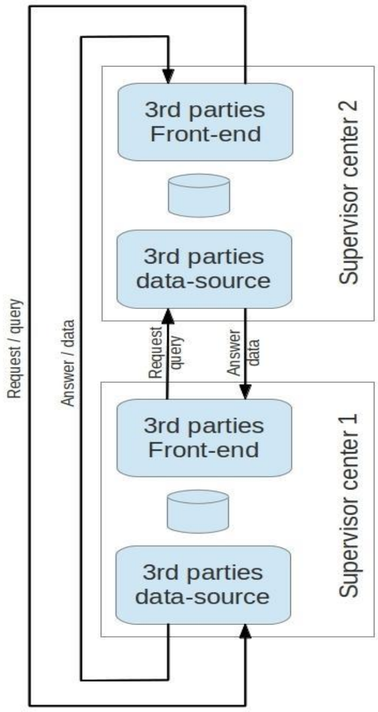


Figure 75: The whole system architecture for the center-to-center data exchange flow.

ID	3PCF_1
Name	Information type
Description	The type of information which can be managed by the 3rd Parties Center Front-End must belong to one of the following categories: • road conditions; • travel times; • accidents; • road works; • traffic conditions; • road weather events; • traffic parameters (speed, flow, density); • public events with impact on traffic; • VMSs messages; • parking areas situation; • air pollution conditions;
Rationale	System design
Type	Functional
Priority	Must

Table 147: Requirement 3PCF_1 (information type).

ID	3PCF_2
Name	Standard communication protocol
Description	The 3rd Parties Center Front-End must support the DATEX II protocol, which is the standard communication protocol for data exchange between traffic centers.
Rationale	Standard interoperability
Type	Non-Functional
Priority	Must

Table 148: Requirement 3PCF_2 (standard communication protocol).

ID	3PCF_3
Name	Distribution license
Description	The data must be released under a proper open data license
Rationale	Open-data approach (compliancy with requirement SC_3).
Type	Non-Functional
Priority	Must

Table 149: Requirement 3PCF_3 (distribution license).

ID	3PCF_4
Name	Client identification
Description	The 3rd Parties Center Front-End must verify the identity and the authorization of its clients.
Rationale	To check which authorized control centre is making access to the data exposed by the Supervisor Centre
Type	Non-functional
Priority	Must

Table 150: Requirement 3PCF_4 (client identification).

ID	3PCF_5
Name	Log records storage
Description	The 3rd parties front-end should keep trace (i.e. produce and store logs) of the incoming requests.
Rationale	To keep trace of the data exchange flow between traffic centers, which could be used in case of responsibility issues.
Type	Non-functional
Priority	Should

Table 151: Requirement 3PCF_5 (log records storage).

7.6.2 Variable Message Signs Front-End (VMSF)

The Variable Message Signs Front-End (VMSF) is simply in charge of delivering to a specific set of VMSs specific messages to travelers that are defined and coordinated by the Supervisor Centre operators during the post-elaboration task..

It is worth noting that here VMSs are intended as real-time information VMSs only, i.e. the ones which have the capability to display general textual and or numerical information. Real-time local data VMSs (e.g. the ones which are used in correspondence of traffic lights in order to display the correspondent phase cycles) are therefore not considered out of the scope of this analysis.

ID	VMSF_1
Name	VMSs connection
Description	The Variable Message Signs Front-End (VMSF) must be connected to the control system managing all VMSs that are under the supervision of the Supervisor Centre.
Rationale	System design
Type	Functional
Priority	Must

Table 152: Requirement VMSF_1 (VMSs connection).

ID	VMSF_2
Name	VMSs messages forwarding service
Description	The Variable Message Signs Front-End (VMSF) must receive the updated messages from the database through the Data Center Dispatcher and deliver them to the proper set of indicated VMSs.
Rationale	System design
Type	Functional
Priority	Must

Table 153: Requirement VMSF_2 (VMSs messages forwarding service).

ID	VMSF_3
Name	VMSs maintenance support
Description	The Variable Message Signs Front-End (VMSF) must be able to receive warnings and/or alarms from each VMS and deliver them to the Supervisor Centre again. On the other side, a Supervisor Centre operator must be in the condition to interrogate a VMS through the Data Center Dispatcher and the front-end in order to receive information about its actual functioning status.
Rationale	Remote control and maintenance of VMSs
Type	Functional
Priority	Must

Table 154: Requirement VMSF_3 (VMSs maintenance support).

ID	VMSF_4
Name	Standard communication protocol
Description	The Variable Message Signs Front-End (VMSF) should support the German standard TLS or in alternative the Roadside Message Protocol (RSMP) as reference data exchange protocol with the VMSs.
Rationale	Standard interoperability
Type	Non-functional
Priority	Should

Table 155: Requirement VMSF_4 (standard communication protocol).

ID	VMSF_5
Name	VMSs information management
Description	The Variable Message Signs Front-End (VMSF) should be able to associate to each VMS the following information: ● position; ● ID; ● screen size; ● type;
Rationale	The front-end should be able to adapt the delivery of the messages as a function of its internal knowledge of the VMS network.
Type	Non-functional
Priority	Should

Table 156: Requirement VMSF_5 (VMSs information managemnt).

7.6.3 *Traffic Lights Center Front-End (TLCF)*

The Traffic Light Center Front-End (TLCF) is in charge of properly formatting and then sending the details of the new traffic light timing phases to the traffic light center. The revised traffic light plans are defined at the Data Center Layer during the post-elaboration task and are sent by this front-end to the traffic light center where they are received, decoded, and finally applied.

ID	TLCF_1
Name	Traffic lights dynamic regulation forwarding service
Description	The Traffic Light Center Front-End must receive on-demand from the Data Center Dispatcher the dynamic traffic lights cycles regulations to be applied on one or more traffic lights, check that the reference data packets are formatted as expected, and immediately forward them to the traffic lights center, which is the system component in charge of controlling and maintaining all the traffic lights within the city of Bolzano.
Rationale	System design
Type	Functional
Priority	Must

Table 157: Requirement TLCF_1 (traffic lights dynamic regulation forwarding service).

ID	TLCF_2
Name	Traffic lights centre warnings management
Description	The Traffic Light Center Front-End must be able to receive any warning coming from the traffic lights center concerning any kind of problems in the actuation of a specific cycle regulation. These warnings must be immediately forwarded back to the database through the Data Center Dispatcher.
Rationale	Verification of the effective application of a specific traffic lights cycle regulation
Type	Functional
Priority	Must

Table 158: Requirement TLCF_2 (traffic lights centre warnings management).

ID	TLCF_3
Name	Traffic lights regulation data packet format
Description	Each traffic light regulation that is received by the Traffic Light Center Front-End must be managed through a data packet containing at least the following fields: • isolated / coordinated regulation; • ID(s) of reference traffic lights covered by the present regulation; • new cycle length; • new intervals; • new offset (in case of coordinated regulation).
Rationale	Each traffic light regulation must contain all necessary information in order to be actuated as expected.
Type	Functional
Priority	Must

Table 159: Requirement TLCF_3 (traffic lights regulation data packet format).

ID	TLCF_4
Name	Traffic lights centre acknowledgments management
Description	The traffic light center should be able to send an acknowledgment for each delivered regulation that has been positively actuated.
Rationale	Confirmation of the effective application of a specific traffic lights cycle regulation

Type	Functional
Priority	Should

Table 160: Requirement TLCF_4 (traffic lights centre acknowledgments management).

ID	TLCF_5
Name	Standard communication protocol
Description	The Traffic Light Center Front-End should support the Roadside Message Protocol (RSMP) as reference data exchange protocol with the traffic lights.
Rationale	Standard interoperability
Type	Non-functional
Priority	Should

Table 161: Requirement TLCF_5 (standard communication protocol).

ID	TLCF_6
Name	Traffic lights information management
Description	The Traffic Light Center Front-End should be able to associate to each traffic light the following information: ● position; ● ID; ● current status.
Rationale	The front-end should be able to adapt the delivery of the messages as a function of its internal knowledge of the traffic lights network.
Type	Non-functional
Priority	Should

Table 162: Requirement TLCF_6 (traffic lights information management).

7.6.4 Public Broadcast Channels Front-End (PBCF)

The Public Broadcast Channels Front-End (PBCF) is in charge of delivering info-mobility information about the current traffic and environmental situation in the city to one or more broadcast channels, so that it can be properly transmitted over local radio/TV networks and received by the local traveler even on board of his/her car. The information to be published has to be organized and formatted according to the broadcast transmission requirements and by using well defined and documented protocols.

ID	PBCF_1
Name	Information type
Description	The Public Broadcast Channels Front-End must receive from the Supervisor Centre through the Data Center Dispatcher only the set of information which is reasonable to distribute over a broadcast channel. It must cover only fresh information related to the current (or predicted) situation and not directly consider historical data.
Rationale	Broadcast channels are suited to deliver few contents but very rich of information, which can really help drivers and travelers during their trip, in particular en-route.
Type	Functional
Priority	Must

Table 163: Requirement PBCF_1 (information type).

ID	PBCF_2
Name	Information formatting and forwarding service
Description	The Public Broadcast Channels Front-End must properly format the validated data

	received on a periodical basis from the Supervisor Centre through the Data Center Dispatcher and forward it to the broadcast distribution channels.
Rationale	System design
Type	Functional
Priority	Must

Table 164: Requirement PBCF_2 (information formatting and forwarding service).

ID	PBCF_3
Name	Broadcast transmission communication technology independency
Description	The Public Broadcast Channels Front-End must be independent from the communication technology used for the broadcast technology, which can be analog (e.g. FM radio) or digital (e.g. DAB, DAB+, DVB-SH, DVB-T) and suited for different reception scenarios (i.e. mobile or static reception, depending from the speed of the receiver).
Rationale	System design
Type	Functional
Priority	Must

Table 165: Requirement PBCF_3 (broadcast transmission communication technology independency).

ID	PBCF_4
Name	Standard communication protocols
Description	The Public Broadcast Channels Front-End must be able to support one or more communication protocols used for the distribution of info-mobility information over a broadcast channel, like for example RDS-TMC and TPEG binary.
Rationale	Standard interoperability
Type	Non-Functional
Priority	Must

Table 166: Requirement PBCF_4 (standard communication protocols).

7.6.5 Public IP Channels Front-End (PICF)

The Public IP Channels Front-End (PICF) represents the unique front-end for providing the validated data and information to general and public external resources available over the Internet such as websites and smartphone applications through open standard services and interfaces.

ID	PICF_1
Name	Data and information type
Description	The Public IP Channels Front-End must have access through the Data Center Dispatcher to all type of data and information managed by the Data Center Layer (traffic / environmental, current / historical, etc.) but only to the one which is validated and elaborated, i.e. which have passed through all elaboration chain.
Rationale	Published data must be reliable and consistent.
Type	Functional
Priority	Must

Table 167: Requirement PICF_1 (data and information type).

ID	PICF_2
Name	Data and information formatting and forwarding service
Description	The Public IP Channels Front-End must be able to receive on-demand and/or periodic

	requests coming from the external clients, get the validated data and information from the Supervisor Centre through the Data Center Dispatcher, and finally format and deliver it accordingly, all this by using well defined interfaces (i.e., web-services).
Rationale	System design
Type	Functional
Priority	Must

Table 168: Requirement PICF_2 (data and information formatting and forwarding service).

ID	PICF_3
Name	Exploitation opportunities
Description	The Public IP Channels Front-End the Internet such as websites and smartphone applications, but also to publish the validated data according to the open data approach.
Rationale	The open data approach allows to multiply the info-mobility information distribution and to foster local innovation.
Type	Functional
Priority	Must

Table 169: Requirement PICF_3 (exploitation opportunities).

ID	PICF_4
Name	Standard communication protocols
Description	The Public IP Channels Front-End must support standard web communication languages (e.g. XML) and be able to support one or more communication protocols used for the distribution of info-mobility information over an IP channel, like for example TPEG-ML.
Rationale	Standard interoperability
Type	Non-Functional
Priority	Must

Table 170: Requirement PICF_4 (standard communication protocols).

ID	PICF_5
Name	Open data distribution license
Description	The Public IP Channels Front-End must release the data according to a well-defined open data license.
Rationale	The end-users must exactly know how they can proper use the data.
Type	Non-Functional
Priority	Must

Table 171: Requirement PICF_5 (open data distribution license).

Conclusions

The deliverable has presented:

- a baseline assessment of the starting situation, which will be used as main reference in order to evaluate the environmental benefits produced by the INTEGREEN system;

- the requirements of the INTEGREEN system, in particular of the components at the Supervisor Centre.

The report has put in evidence the significant role that INTEGREEN can have in order to reach the ambitious target in terms of reduction of the environmental impact produced by mobility and traffic inefficiencies which the Municipality of Bolzano has set. While the Urban Mobility Plan addresses these issues through traditional, long-term and expensive solutions, the INTEGREEN project can provide novel, short-term and (possibly) low-cost solutions which can complement the first ones, going more in the direction of *how to optimal allocate the available road infrastructure resources* rather than to *expand them in order to match the increasing demand*. Transit and heavy traffic flows can be intelligently managed on the base of the current, predicted and historical information.

The air pollution levels detected by the fixed monitoring stations in the last years offer a clear evidence of the necessity to properly manage in first place the high levels of NO_x, but also keeping under control the PM emissions. NO_x pollutants represent today in Bolzano the main concern for both human health and urban natural environment in terms of air quality, and traffic source is a relevant component in that. A proper introduction of intelligent eco-oriented traffic strategies, if complemented with proper local policies, is in the condition to decrease the emissions - and thus the accumulation - of nitrogen oxides.

Preliminary local studies, analysed in the previous paragraphs, have provided reference values for an initial assessment of the starting situation for INTEGREEN. Through this analysis, the following aspects have emerged:

- the methodologies used in the study of EURAC (for CO_2 emissions) and CISMA (for NO_X and PM_{10} emissions) should be considered and applied during the project in order to obtain comparable results at a macroscopic level and properly evaluate the environmental improvements of the project;

- microscopic patterns, which are strongly related to the project's objectives, have to be specifically included when CO_2 is taken into consideration: for example, the EURAC study does not take in consideration microscopic factors like navigation, driving style, traffic conditions, road peculiarities, that can significantly impact on the CO_2 emissions produced during a travel;

- an evident, real-time basis assessment of the correlation of traffic and air pollution is not today available: traffic peaks and pollution hotspots have never been considered with a clear, integrated approach.

This preliminary measurement campaign allowed to empirically confirm that all evaluated microscopic factors have a certain impact on the amount of CO_2 emissions produced by vehicles moving in the urban area of Bolzano, and all these are source of inefficiency that can be properly addressed by the INTEGREEN project. This campaign also put in evidence the strong temporal variability of traffic conditions within the city, which suggests as possible efficiency measure to foster *temporal* navigation strategies (i.e. recommending travelers to start their travels at a specific time) instead of traditional *spatial* navigation strategies (i.e. recommending travelers the best route in the current situation), which could be quite problematic and counter-productive for a rather small environment like the one of the city of Bolzano.

The holistic approach which has been considered in this analysis has allowed to take in consideration all different aspects (technical and organizational) of the proposed intervention, and will significantly simplify the executive design and implementation of the system.

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