The INTEGREEN approach for the assessment of environmental traffic management policies

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Abstract

We present the novel approach proposed by the INTEGREEN project concerning the assessment of dynamic environmental traffic management policies that are applied in urban areas. The approach is based on an integrated monitoring system which collects distributed data concerning traffic and air pollution by means of both static roadside stations and probe vehicles. The monitoring system makes not only possible to early identify critical situations happening on road network (e.g. traffic jams and air pollution hotspots) and thus to efficiently activate the proper preventive or reactive traffic policies, but also to quantify the impact that those have had on the urban environment. First empirical data collection campaigns based on fuel consumption data and vehicular travel time estimates carried out in the Italian town of Bolzano have highlighted the traffic inefficiencies profiles which are typical for an urban, touristic alpine area that can be addressed by means of this approach.

KEYWORDS:
Environmental traffic management, probe data from vehicles, real-time travel information, Bluetooth-based travel times estimation

Introduction

Bolzano is a medium town characterized by a relevant modal split, namely only the 33,9% of local travelers chooses a motorized vehicle for an internal urban trip [1]. On the other hand, the city suffers of heavy seasonal traffic congestion phenomena influenced by particular conditions such as bad weather conditions and/or tourist flows. Urban traffic, summed up with the intense transit flows over the A22 highway, are the main local emission source of NO_2. The particular orographic nature of the city significantly obstructs the dispersion of the air pollutants in the atmosphere (Figure 1), and is a key factor for the high accumulation levels of this pollutant within the urban environment, which have been exceeding since several years the annual average upped bound defined by law of 40 [g/m^3]. The transport system in Bolzano is also a main source of greenhouse gas emissions, and are responsible for the 31% of the whole CO_2 emissions with a production of about 3.0 [tons/inhabitant*year] [2]. The Municipality of Bolzano has set the ambitious target to reduce emissions from 9.7 up to 2.0 [tons/inhabitant*year] by 2030 by means of a set of integrated measures, which include among long-term transportation improvements an environmental-oriented approach in the management of mobility demand and control of traffic conditions.

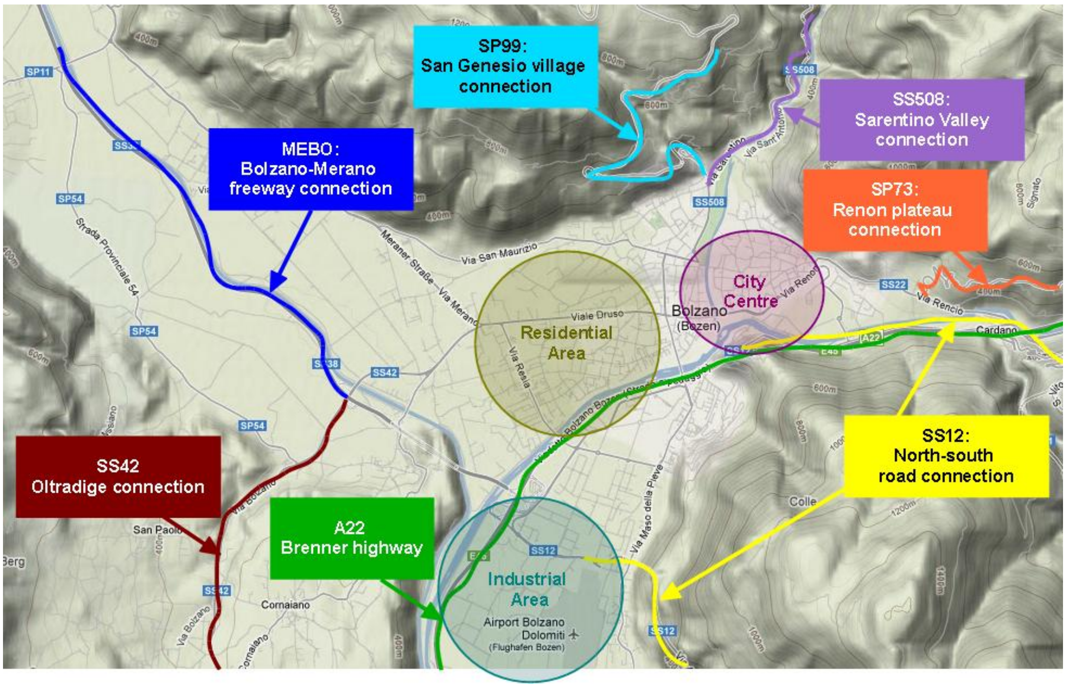

Figure 1: The road infrastructure scenario of the city of Bolzano.

International state of the art

Environmental traffic management is a rather novel discipline in the field of ITS which has already proven its potential benefits on European urban areas, as firstly demonstrated within research projects such as iQ mobility [3], and MESSAGE [4], where the potential of considering mobile probe vehicles able to collect distributed environmental data for this kind of application has been first assessed. Today, several research projects such as CARBOTRAF [5] and AMITRAN [6] are facing the challenge on how to (i) adaptively influence traffic on a real-time in order to reduce the air pollution levels and/or the greenhouse gas emissions, and (ii) quantitatively assess the impact of these dynamic adaptions.

Furthermore, cooperative ITS (C-ITS) have already demonstrated their huge potential contribution in this field. In particular, the eCoMove project is proposing a holistic cooperative ITS architecture which specifically aims at tackling energy inefficiencies in three different domains, namely (i) driving behaviors, by introducing a virtual coach able to give personalized recommendations based on individual driving historical records; (ii) routing choices, by creating an application tool able to discover the lowest energy route on a real-time basis, and (iii) traffic management, by proposing a distributed platform able to apply traffic control measures (e.g. dynamic changes in traffic lights phases) which are globally optimum from an environmental point of view [7].

The INTEGREEN approach

The INTEGREEN project aims to apply the concepts and the solutions available at the state-of-art in the field of environmental traffic management by introducing novel solutions that target the specific needs of the city of Bolzano. The innovation proposed in INTEGREEN is both technical and social, since (i) a fully integrated static and mobile traffic and environmental monitoring system is proposed in order to quantitatively assess the environmental impact of urban traffic, and (ii) the local travelers are directly influenced in their travel decisions by means of real-time travel and traffic information which is spread with the intention to increase the environmental awareness of their travel choices (Figure 2).

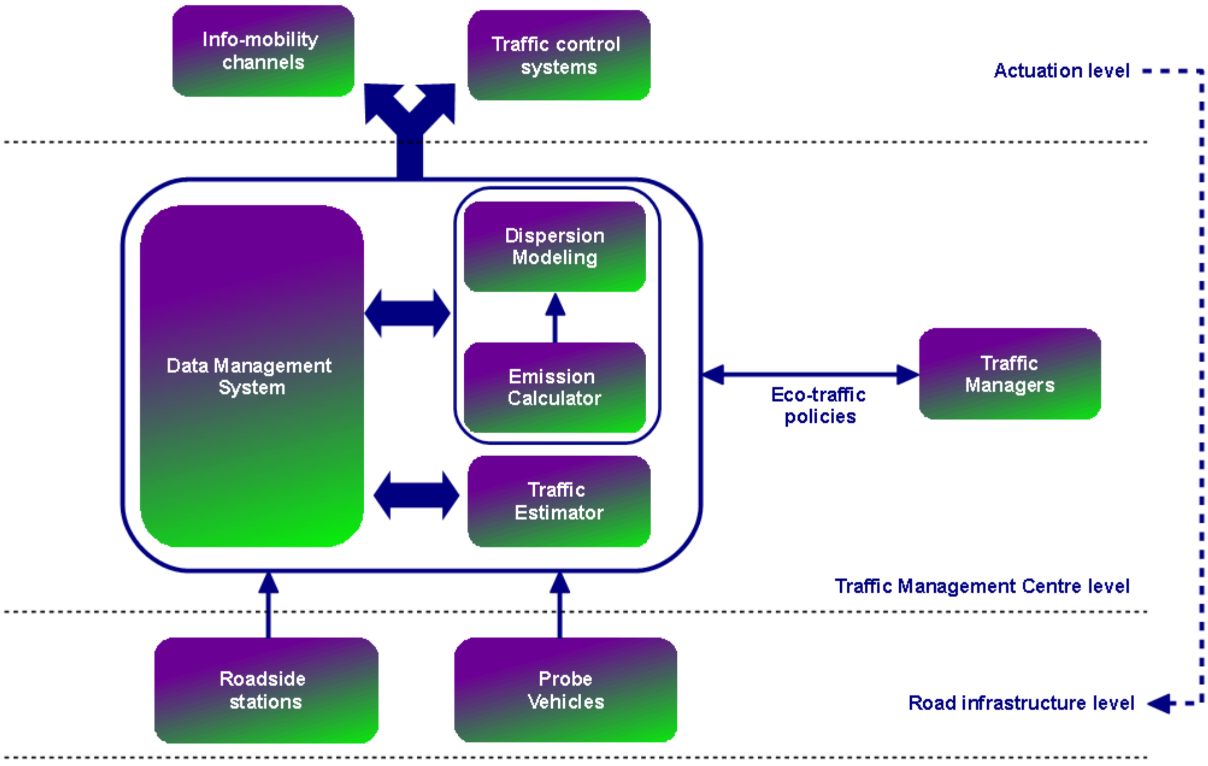

Figure 2: The simplified architecture of the INTEGREEN system.

Two demonstrative probe vehicles for monitoring both traffic and environmental parameters will be introduced as well as a certain number of traffic and environmental roadside stations covering a test route where the approach will be tested and validated. Eco-friendly dynamic traffic policies coordinated by the Traffic Management Centre (TMC) of the city will cover heterogeneous aspects, considering traffic control measures (e.g. traffic lights regulation, variable speed limits change, etc.), routing measures (i.e. by distributing the traffic flows over specific routes) and mobility measures (i.e. by favouring smarter travel choices and plans).

Preliminary evaluation studies

An initial baseline assessment study was performed with the objective to quantify the local traffic inefficiencies and to balance them as a function of their environmental impact. In particular, the goal of this analysis was to identify a set of reference use cases and as a consequence a basic list of requirements to be addressed by the INTEGREEN system [1]. As part of this study, a simple measurement campaign was organized in order to quantitatively evaluate the local impact of several microscopic factors influencing the environmental impact of vehicular travels, and more specifically (i) traffic levels, (ii) traffic control and actuation systems; (iii) driving style, (iv) travel start time choice and (v) navigation factor. Fuel consumptions were measured by means of a commercial on-board unit and collected over a test route of about 8.8 [km] (Figure 3). The navigation factor was specifically assessed through additional tests on two different routes sharing the same origin/destination couple.Twelve different data sets were collected in May 2012 during this empirical experience by driving repeatedly in a variety of different traffic, weather and driving conditions and at different times of the day. The driving tests were carried out by means of a naturalistic approach, with the same driver accompanied by a driving coach.

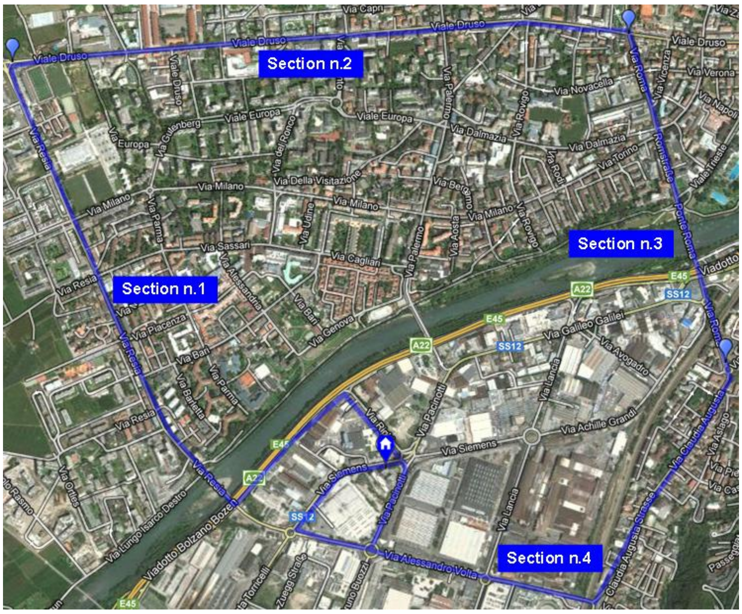

Figure 3: The test route for the initial fuel consumption measurement campaign.

One of the main results of this campaign was the assessment of the high potential of applying more efficient temporal routing strategies, which allow traffic levels to be more distributed in the temporal domain rather in the spatial one (Figure 4). This statement, which is particularly evident during peak hours and/or weather phenomena (in which a relevant number of commuter change their typical travel mode, e.g. bicycle), can be read as a direct and natural consequence of the urban scenario of interest, with a reduced number of road alternatives and a very reduced capability to manage intense traffic peaks. This result is particularly evident if we compare test 1/2 and test 2/2, which were carried out with a time space of only 30 minutes. Test 1/2 was clearly affected by the local, typical morning traffic jam, which was amplified on that occasion by severe weather conditions in which this data set was collected. A driving test repeated at a short time distance (with a smoother driving style) produced a first highlight of the high temporal variability character of traffic fluency in the case study scenario.

Travel time estimation measurement campaign

The results of the preliminary measurement campaign raised the necessity to start a more extensive measurement campaign capable of characterizing the highly dynamic behavior of vehicular travel times with a sufficient resolution in the time domain. This task has been carried out by an experimental travel times monitoring system based on the detection of the Bluetooth in-car devices [8]. Each portable probe is able to couple the timestamp with an unique identifier which is associated to each detected vehicle. By combining the patterns collected by two (or more) probes, it is possible to estimate the average travel time on a specific reference route. This technology, whose main attractiveness is to be non-invasive, low-cost and energy efficient, can lead, if effectively integrated with other traffic monitoring solutions (e.g. ANPR cameras, non-invasive traffic detectors) to an extended roadside monitoring network able to feed advanced central applications. One example is the possibility to feed a matrix where the individual items dynamically represent the current vehicle average travel times between two points calculated over a certain time frame. These matrices can also provide very valuable offline inputs for the O/D matrixes, those invaluable entities that any traffic engineer wants to play with in order to calibrate transportation demand/offer models.

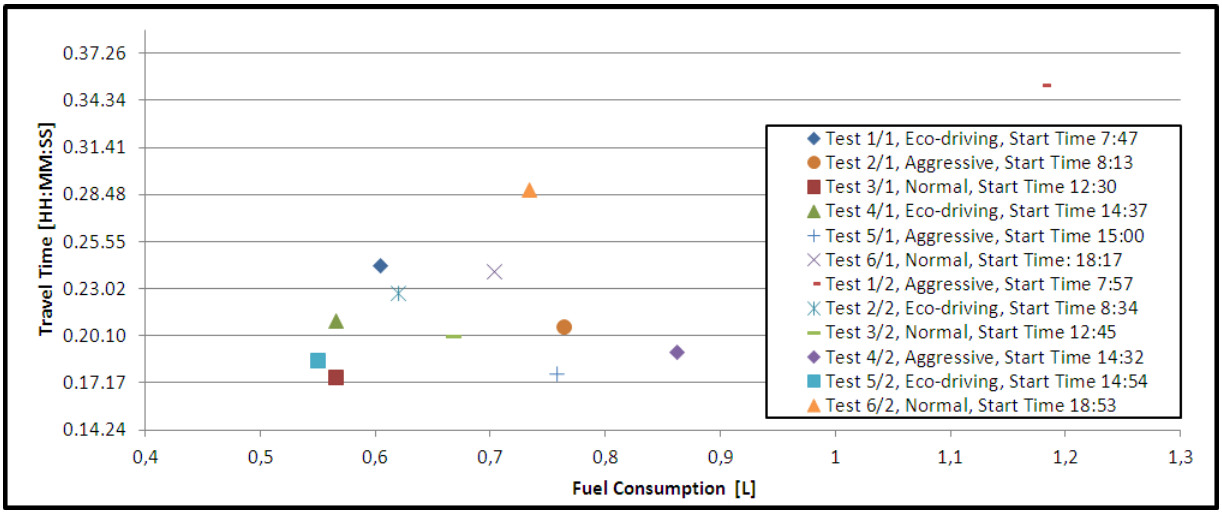

Figure 4: Empirical fuel consumptions versus travel times.

This data can be obviously very precious for online traffic control operations: traffic jams can be rapidly detected and managed, and mathematical models can be run in order to calculate short-term traffic state predictions.

Data analysis complexity

The computation of an average travel time which is representative of all those cars detected at two monitored areas is less simple as it can appear at a first glance. One can simply think to calculate the average among all the values gathered, however, this method is not robust enough due to the unforeseeable and versatile way in which cars behave in a city, namely there could be a significant amount of vehicles stopping on the way, i.e. to carry out some individual errands. Given these premises, using all the data gathered can lead to wrong results, since the average travel time must be representative only of those cars that drive straight to the destination. In other words, how is it possible understand that a car had a stop for shopping instead of being stuck in the traffic? Before delving into the details of how the data can be analysed and validated, the following definitions are introduced:

- *a "**record**" is a data packet composed by three fields: a station identifier, a unique car identifier and the timestamp of the detection;*
- *a "match" is a couple of two records with the same car identifier but different station identifiers (O- origin, D- destination); a match is considered "valid" if and only if (i) the record at station O is detected in time before station D, and (ii) in the time interval identified by its two timestamps there is no other record detected by at least one of the two monitoring stations having the same car identifier;*
- *the "**elapsed time**" is defined as the relative difference between the timestamps associated to each valid match.*

Given the fact that the monitoring infrastructure is not able to automatically cut out cars that have made one or more stops between the two detection points ("*valid indirect matches*") from those that pass strait ("*valid direct matches*"), a proper validation and elaboration process is demanded in order to accomplish this task. The objective is to automatically exclude the indirect matches from the valid matches data set, and calculate an appropriate estimation of the current travel time. The process we propose for each possible (O,D) path is the following: (i) the dataset is divided into temporal frames of the same amplitude; (ii) all valid matches are identified and grouped as a function of the timestamp of the record detected at station O; (iii) a reference *travel time indicator* is computed for each temporal frame and (iv) a travel time indicator validation is performed. Three standard indicators have been considered, namely (i) the "***lower bound***", which returns the lowest elapsed time, (ii) the "***arithmetic mean"***, which returns the arithmetic mean of all elapsed times, and (iii) the "***mode"***, which is calculated by returning an indicative value of the time interval where the occurrence of all elapsed times is maximum.All three indicators are unfortunately subjected to the unforeseeable character of travel demand. The lower bound is not fully representative of the whole traffic conditions, since it can report particular car travels which might have taken advantage of a green wave or even worst that might have driven over the speeds limits. On the other hand, the arithmetic mean can be higher than the real value since it might take in consideration valid indirect matches. Finally, the mode is at first sight the most robust indicator, but unfortunately diverges when its value tends to be representative of valid indirect matches. This pattern can be quite common when in the path between the two monitoring stations relevant attraction points are located. The solution proposed for the validation step considers the following constraint*:*

Given two consecutive modes m_t *and* m_{t+1}*, where t and t+1 are the median values of the correspondent temporal frames, then a mode is "valid" if and only if:*

$$t + m_t < (t+1) + m_{t+1}$$

A full set of modes values is considered "valid" if the above constraint is satisfied all over the entire set of temporal frames. In order to accomplish this, a recursive algorithm is executed, which allows the invalid matches to be identified and finally removed. Moreover, this method leverages us from using predefined range of correctness, threshold and numerical approximations which give to our data model a stronger elasticity to correctly work with the very dynamic traffic patterns the city of Bolzano has.

Measurement campaign results

An extensive measurement campaign was carried out during the period November 2012 – January 2013 (Figure 5).

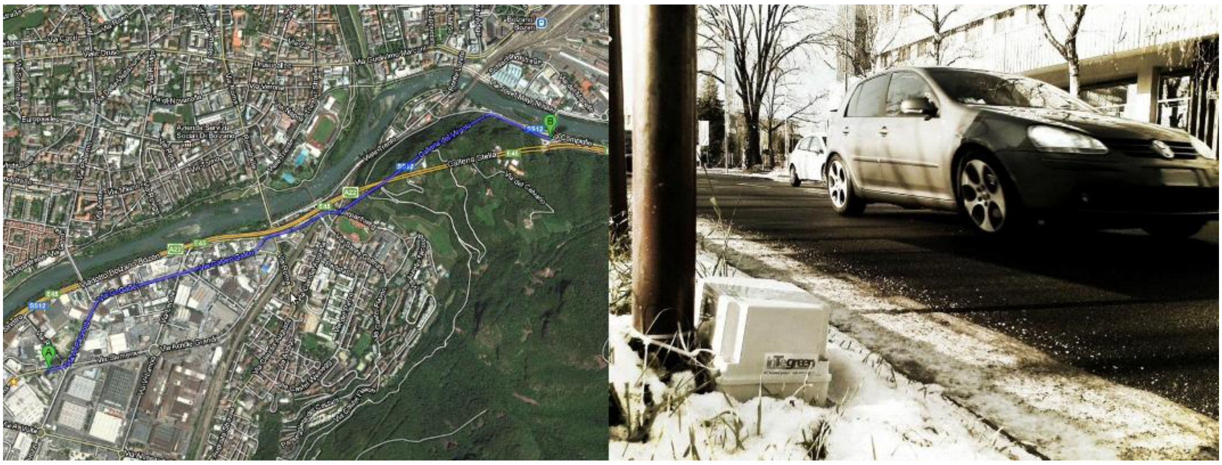

Figure 5: The travel times measurement campaign: test route and roadside unit.

During this period, a significant amount of tourist flows is used to join the city and visit the local Christmas market, causing as a consequence an increase in the overloading of the urban road network and the appearance of several episodes of traffic jams. This is particular true during specific days anticipating long weekends and public holidays. The monitoring activity has covered a very traveled two / three lanes route characterized by an average traffic flow of about 2.000 [vehicles/hour]. We placed our Bluetooth monitoring probes about 3 [km] far away from one another in a road stretch characterized by the presence of four traffic lights, all of them working on demand [9]. This monitoring technique has proofed of being able to detect at least the 25% up to the 42% of the whole traffic flows. Although in normal traffic conditions the average elapsed time is about 200 [s], this value is rarely reached, as shown in Table 1, where the mode travel indicator values are reported. For the sake of readability, we have shown only the results belonging to a subset of significant comparable days, namely two different Thursdays and three Fridays, and all this for a reduced temporal window (between 4:00 PM and 6:30 PM) [1].

Table 1: A significant subset of mode travel times values.

Days vs temporal frame start	16^{00}	16^{15}	16^{30}	16^{45}	17^{00}	17^{15}	17^{30}	17^{45}	18^{00}	18^{15}
Friday, 07th Dec 2012	4:02	6:19	6:07	4:45	4:52	5:18	9:30	10:12	4:59	4:43
Friday, 14th Dec 2012	3:57	3:58	4:21	4:45	4:47	4:48	4:26	4:12	3:41	3:20
Friday, 25th Jan. 2013	3:17	3:48	3:26	4:29	4:00	4:17	4:17	3:49	3:34	3:59
Thursday, 6th Dec. 2013	3:47	3:25	3:43	4:23	4:30	5:17	4:23	4:11	5:28	3:13
Thursday, 13th Dec. 2013	3:14	3:16	3:40	3:09	3:56	3:42	5:29	4:48	4:09	3:47

Finally, in Figure 6 we have plotted the travel time mode values of the datasets related to the Fridays presented above. Although the datasets refer to the same week day, the trends we computed are clearly different, in particular during the late afternoon.

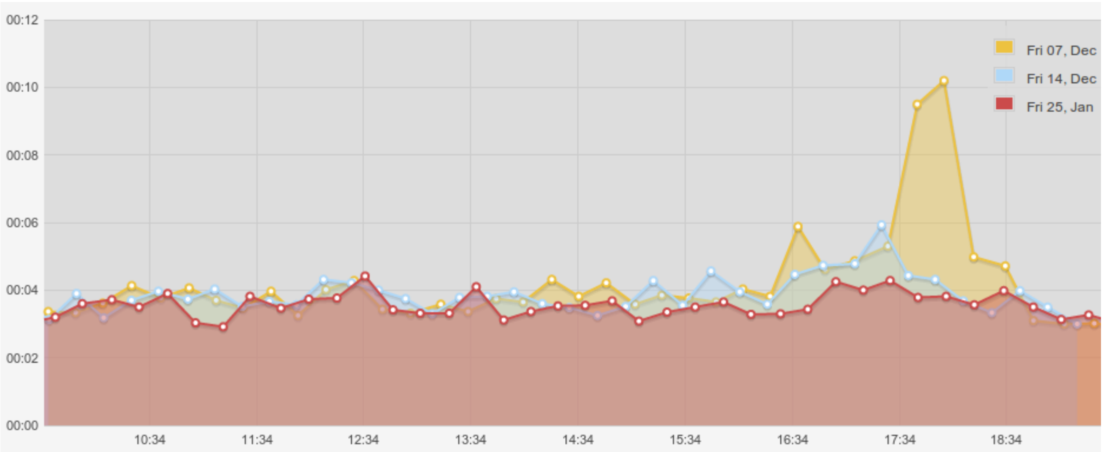

Figure 6: Travel times trends obtained during significant monitoring days.

As a result of the plotted datasets, we can observe that (i) the travel time indicator values calculated during the Christmas market period (December) are higher than the ones observed during a non-touristic period (January), (ii) the evident peak of Friday 7th falls exactly the day before a public holiday, in which the city is used to experience an amplification in the local

[1] Interested users are invited to visit http://traffic.integreen-life.bz.it for the full dataset collection.

travel demand, and (iii) as measured in the fuel consumption campaign, the shift to a saturation condition of the road network (and vice versa) can be obtained in a very fast way.

Conclusions and next steps

The initial measurement campaigns of the INTEGREEN project have pointed out the specific peculiarities of the traffic in the city of Bolzano, in particular its seasonal and high variable character. The project activities are now concentrating on the design and development of this experimental platform, in particular the focus is on how to best endorse the impressive amount of information which can be extracted by the joint elaboration of heterogeneous data sources availing of different state-of-art monitoring technologies, both at a roadside level and on-board. Further dedicated measurement campaigns are planned with the goal of deepening the local correlation between traffic conditions, travel times and air pollution levels, in particular in order to (i) detect peak situations in correspondence of traffic congestion phenomena and very intense stop&go conditions, and (ii) understand how dynamic traffic policies can contribute in order to locally mitigate these negative phenomena. Thanks to the proposed system, INTEGREEN is going to locally create the enabling infrastructure for further exploiting this integrated approach and to deploy it by means of cooperative technologies.

Acknowledgments

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