Paper ID EU-TP1487

First results and lessons-learnt on air quality and traffic management from the application of VSL within the BrennerLEC project

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Abstract

This paper presents the first results and lessons learnt of the LIFE “BrennerLEC” project, in which an advanced “environmental traffic management” concept is under testing on the Italian A22 (Brennero – Modena) highway [1]. The application of variable speed limits (VSL) for air quality purposes, despite the absence of enforcement systems, is demonstrating its effectiveness to reduce the concentration of traffic-related pollutants: on average, with speeds reductions of about 15 [km/h] nitrogen oxides concentrations at the side of the highway are reduced in the order of 10%. VSL applied during intense traffic flow days are also showing promising results: in comparison with traditional traffic control strategies, an increase of about 8% of the road capacity has been estimated. Quantitative traffic- / environmental driven triggers are currently under study in order to automatically activate VSL so to achieve the best compromise between traffic fluency, air quality conditions and duration of VSL.

Keywords:

Environmental traffic management, traffic / air quality correlation, VSL, stick & carrot approach

1. First pilot activities with VSL applied for air quality purposes

The first set of traffic management policies investigated by the project covers the application of VSL for air quality purposes. Such policies are tested in a limited area of the A22 highway, more specifically in a road stretch of about 20 [km] between the tolling gates of Egna/Ora and S.Michele called “BLEC-AQ”.

1.1 Test site setting

The first phase of testing is limited to a smaller stretch of the BLEC-AQ test area, characterized by a length of about 5 [km] only and supported by the infrastructure which is graphically presented in Figure 1. The reduction of the speed limit is done in two steps through fixed Variable Message Signs (VMS): speeds are first reduced from 130 [km/h] to 110 [km/h] and then finally to 100 [km/h]. The test area is characterized by two complete air quality / traffic monitoring sites: the one positioned at km 103+700 has the function to measure the effects of the speed reduction measure, while the one placed at km 107+800 gives the possibility to investigate the effects of the measure just before / after the test area and to correlate phenomena not only in the temporal domain but also in the spatial domain. Mobile air quality stations, compliant with the current rules for the measurement of air quality levels, are used for the environmental monitoring; traffic monitoring is performed by means of traditional inductive loops. Drivers have been induced to observe speed limits by highlighting on the VMS the monitoring activities performed within the test stretch. No specific enforcement measure has been put in place in this phase: on one side because this is currently not possible in Italy, due to the impossibility for the road operator to apply VSL for environmental purposes; on the other side the aim was to check the initial natural reaction of drivers while driving under these new conditions.

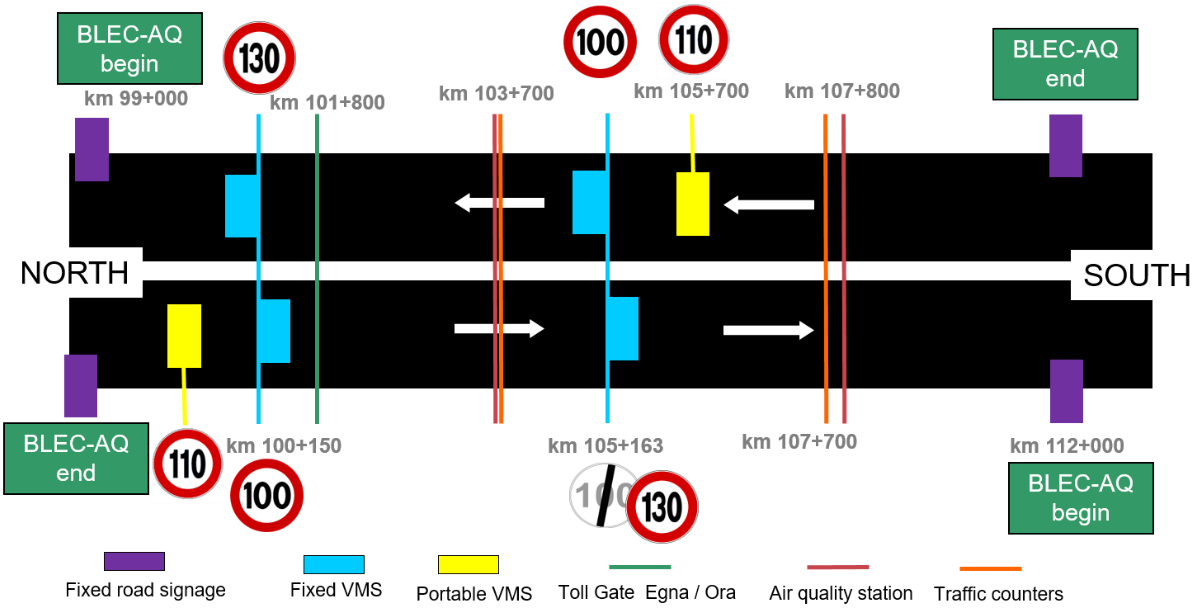

Figure 1 – Test site setting for the first tests with VSL applied for air quality purposes.

Figure 2 – Message displayed on the "entry VMS" during test sessions in the BLEC-AQ test stretch.

1.2 Test session organization

The first phase of testing has been organized within a temporal scope of a year. The objective has been to apply VSL on the base of a reference calendar, so to collect a sufficient number of hours that are statistically representative of a whole year in terms of traffic and meteorological conditions, periods of the day and year's seasons. As a result, by only considering air quality measurements collected during these tests, it is possible to get a first quantitative result of the environmental impact that can be produced if such speed limits would be applied in a fixed way for an entire year period. According to reference EU and national guidelines (in particular the Directive 2008/50/EC), such statistical yearly representativeness is achieved by collecting data for at least the 14% of the time (1.200 hours), with a uniform distribution of measurements in time. Field tests have started in April 2017, and have been completed in April 2018. The phase 1 tests were anticipated by preliminary trial tests started in February 2017 in which the infrastructure was tested by considering limited reduction of the speed limits, i.e. 110 [km/h]. A final glance of the amount of tests collected during this phase is reported in Table 1.

Duration of test sessions	1.918 hours
Duration of valid test sessions	1.227 hours
On working days	72%
On holidays and days before holidays	28%
During the summer	27%
During the winter	43%
During the other seasons	30%

Table 1 – Summary of the test sessions carried out so far with VSL applied for air quality purposes.

Due to some technical issues with the VMS and inductive loops, it was not possible to carry out any test sessions in June 2017. Test sessions have been organized with different time intervals and schedules, so to maximize the data collection in different periods of the day and evaluate the reaction of drivers to shorter / longer test sessions. In order to consider a test session "valid" the following criteria have been considered: (i) complete functioning of the test site's equipment; (ii) absence of traffic events which determined the need for a different use of VMS messages; (iii) minimal observance of speed limits by drivers, quantitatively set in terms of average speed limit of light vehicles during the test session lower than 115 [km/h].

1.3 Speed limit compliance

The average speed during test sessions has been 109 [km/h], measured at the monitoring site at km 103+700. The difference with the average speed measured at the monitoring site at km 107+800 has been 14 [km/h]. The reduced speed limit is in general observed by 30% of the light vehicles. Despite this partial result in the speed limits' observance, reduced speed limits have demonstrated to have the effect to overall better regulate traffic conditions, as confirmed by the significant reduction of the variance of the distribution curves presented in the example plot of Figure 3, in which the density distributions of speeds measured at km 103+700 during tests and no tests conditions on a representative test day are compared.

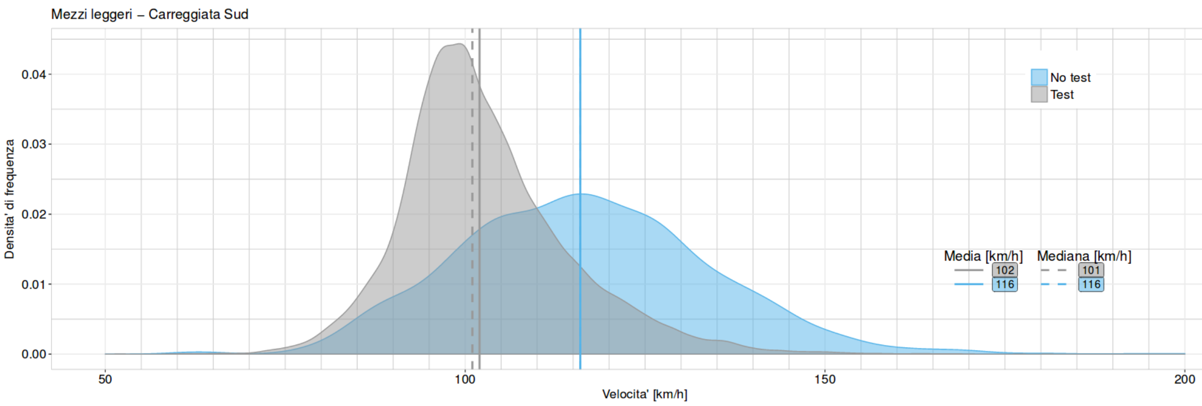

Figure 3 – Density distribution of speeds measured at km 103+700 during tests and no tests conditions (South direction, test 17.07.2017)

1.4 Methodology for the impacts' assessment

The assessment of the environmental impacts has been carried out by considering the air quality measurements referring to a subset of the tests conditions that were considered favourable in order to effectively verify the impact of a reduction of the vehicular speeds' on the concentration of air pollutants. The following criteria have been in particular applied: (i) wind flowing from the highway in direction to the air quality stations; (ii) difference in the average speeds measured at the two monitoring site greater than 10 [km/h]; (iii) minimum amount of flowing traffic, with threshold set to 20 vehicles in 10 minutes (the temporal resolution of the analysis). The resulting sub-dataset is characterized by 730 hours of tests, covering the phases of the day as illustrated in Figure 4.

00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
14	13	10	11	11	10	15	26	28	37	37	38	38	47	46	40	37	40	47	46	45	41	35	20

Figure 4 – Distribution of the subset of the test sessions (in hours) used in the impact assessment of the VSL applied for air quality purposes as a function of the hours of the day.

1.5 Results

The results of this first impact assessment are summarized in Figure 5, which highlights the reduction of NO_2 (nitrogen dioxide) concentrations, measured as difference between the concentrations at km 107+800 and the concentrations at km 103+700. On average, the reduction is quantified in the order of 6 [$\mu g/m^3$], equal to about 10% of the typical concentrations measured at the road side of the highway. The entity of the reductions on NO (nitrogen monoxide), primary pollutant emitted by vehicles, is very similar (Figure 6). The comparison between the averages of the measurements collected in each hour of the day during both test and non-test sessions, filtered according to the same list of aforementioned criteria, gives the possibility to appreciate two aspects (Figure 7). On one side, the periods of the day in which on average the reduction of pollution are higher, which have revealed to be in particular the early afternoon; and on the other side, it confirms that in correspondence of the monitoring site at km

107+800 air pollution concentrations during test and no test sessions show negligible differences, demonstrating the statistical representativeness of the collected sample of data.

00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
1.5	5.3	2.2	-3.1	-0.4	5.1	1.8	-0.6	8.7	9.0	7.2	3.4	2.2	6.3	7.4	10.4	15.9	4.5	11.6	10.9	5.4	0.0	3.0	1.5

Figure 5 – Distribution of the reduction of NO_2 due to dynamic air pollution-induced policies as a function of the hours of the day.

00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
-0.8	5.2	3.8	-1.4	-2.3	4.0	0.9	-3.5	20.8	17.9	13.2	0.8	1.5	5.9	4.4	7.6	11.8	1.4	10.0	11.1	8.1	2.3	6.5	5.2

Figure 6 – Distribution of the reduction of NO due to dynamic air pollution-induced policies as a function of the hours of the day.

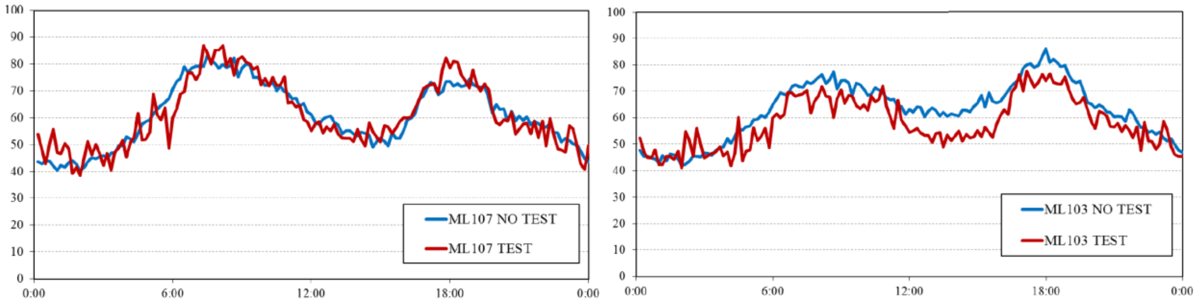

Figure 7 – Average concentrations of NO_2 in correspondence of the monitoring site at km 107+800 (left) and at km 103+700 (right) during test and non-test sessions.

The relevant reductions observed can be understood if directly correlated to the nature of the fleet of vehicles driving on the A22 highway: specific Automatic Number Plate Recognition (ANPR)-based investigations have in fact revealed that on average light vehicles are newer than the one driving on regional and urban streets (more than 25% EURO 6 compared to about 20% in the region and less than 10% of Italy), but more pollutant (76% diesel cars with respect to the local 52% registered diesel vehicles of the regional fleet).

2. First pilot activities with VSL applied traffic control purposes

The second set of measures investigated by the project covers the application of VSL combined with hard shoulder running (HSR) to manage nearly saturated traffic conditions. Such measures are tested in a broader area of the A22 highway, more specifically (at full tests' speed) in a road stretch of about 90 [km] between the tolling gates of Bolzano North and Rovereto South called "BLEC-ENV". Tests are carried out only in South direction due to the infrastructural limitation of the highway in managing HSR.

2.1 Test site setting

The first phase of testing has been limited to a smaller stretch of the BLEC-ENV test area, starting from Trento South; this is at present the only A22 stretch which is fully equipped to manage HSR, thanks to a larger emergency lane and a denser presence of properly equipped VMS, on average every

2-3 [km]. The test area is characterized by a complete air quality / traffic monitoring site, positioned at km 164+400, which aims at highlighting specific impacts on air quality concentrations during particular stop&go conditions, to be compared with similar situations in which traffic flows smoothly. In the test area, additional inductive loops are installed, in particular at km 138+100 and km 156+600. The message displayed on the VMS is very similar to the one used in the first set of policies; most of the VMS in this stretch however displays only the pictogram of the reduced speed limit (Figure 8).

Figure 8 – VSL applied on the BLEC-ENV test stretch.

2.2 Test session organization

The first phase of testing has been organized even in this case with a temporal scope of about a year. The objective has been to try to empirically start to manage nearly saturated traffic conditions in specific test days by means of VSL and to evaluate the benefits obtained by comparing similar situations not managed by this measure. Based on current traffic conditions, operators of the A22 Traffic Management Centre (TMC) have activated VSL first to 110 [km/h] and in certain cases up to 100 and 90 [km/h]. According to traffic, VSL were dynamically activated on a reduced part of the test stretch or on its entirety. The opening of HSR has not been performed yet due to the lack of sufficiently trained protocols for the safety operations in case of accidents.

Field tests have started in March 2017, and have been completed in May 2018. A final glance of the amount of tests collected during this phase is reported in Table 2.

Number of test sessions	34
Number of valid test sessions	23
On summer Saturdays (touristic peaks)	8
On summer Sundays (touristic peaks)	4
In correspondence of other holidays	11
Average duration of each test session	5h 11’

Table 2 – Summary of the test sessions carried out so far with VSL applied for traffic control purposes.

In total, 34 test sessions have been carried out, but some of these have been discarded because affected by accidents or malfunctions of the inductive loops, therefore only 23 test sessions can be considered valid. Most of the test sessions have been executed during the summer period, in which the days with intense occasional traffic flows due to tourists coming towards Italy from the German-speaking countries are more frequent.

2.3 Speed limit compliance

The assessment of the speed limit compliance has been analysed during test days in which traffic conditions were not so saturated, and did not condition too much the possibility of drivers to exceed the applied VSL. Speed data have revealed that in these cases on average about 70% of drivers observe reduced speed limits: a value which is absolutely comparable with the ones observed during non-test conditions. The motivation for this result, quite different from the one obtained with the other measure, is primarily related to the different traffic conditions; the abundant number of VMSs already installed along the test stretch from Trento to Rovereto has surely contributed to the positive observance of the speed limits imposed.

2.4 Methodology for the impacts' assessment

The proposed methodology for the assessment of the impacts associated to this traffic control measure is mainly based on the evaluation of the improvement of **traffic level of services**, characterized with a resolution of 10 minutes as a function of fundamental traffic parameters (speed, density and flow) calculated on the basis of traffic raw data and threshold values that have been empirically estimated on the base of the specific infrastructure settings. Such traffic assessment is then translated in **emission** terms, calculated using the COPERT methodology [2]. Specific favourable situations that have clearly shown traffic and emissions improvements are then further checked in **the air quality** domain by evaluating the data collected by the measurement station positioned at km 164+400, which allow detailed analyses of pollutants such as NO_2, NO, ozone, black carbon and ultrafine particles.

2.5 Preliminary results

The full application of the proposed methodology on top of the collected data set is currently on-going, therefore in this section first initial quantitative indications about the outcome of the tests are only provided. This is also due to the fact that the emission translation of traffic level of services is currently under calibration thanks to the aforementioned characterization of the vehicular fleet driving on the A22 based on specific ANPR-based investigations.

In the first tests the observed result in terms of road capacity management has been in general quite poor because speed limits were activated too late and traffic jams appeared in very short time. The tests of August 26th – 27th were the first in which not only speed limits were anticipated in time, but also further reduced in the steps 100 [km/h] and 90 [km/h]. Results have been quite successfully: despite intense, traffic was more regular for an increased amount of time (estimated in 1-2 hours), before entering in a complete situation of saturation (Figure 9). The anticipation of the application of VSL and the large observance of speed limits of drivers have revealed to be the two key factors for increasing the stability and homogeneity of traffic flows. The plots presented in Figure 10 show the typical situations of intense traffic days successfully managed with VSL. Plots in red, yellow and green relate to days in which average traffic in direction South was respectively lower than 2.500 [vehicles / hour]; between 2.500 and 3.000 [vehicles / hour] and greater than 3.000 [vehicles / hour], respectively; every point represents a 10-minutes measurement. The activation of VSL confirms the ability to increase, at the same boundary conditions (e.g. at a given average speed), the equivalent road capacity of the highway. Preliminary estimations quantify this increase in the order of 8% of the traffic density.

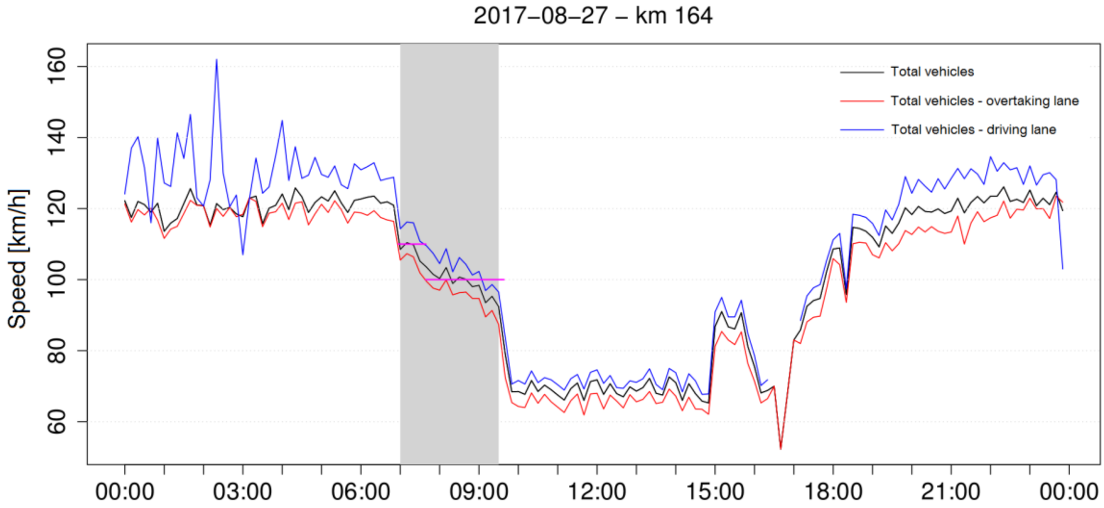

Figure 9 – Temporal average speed evolution at km 164 during a test session with VSL applied for traffic control purposes carried out on August 27th 2017.

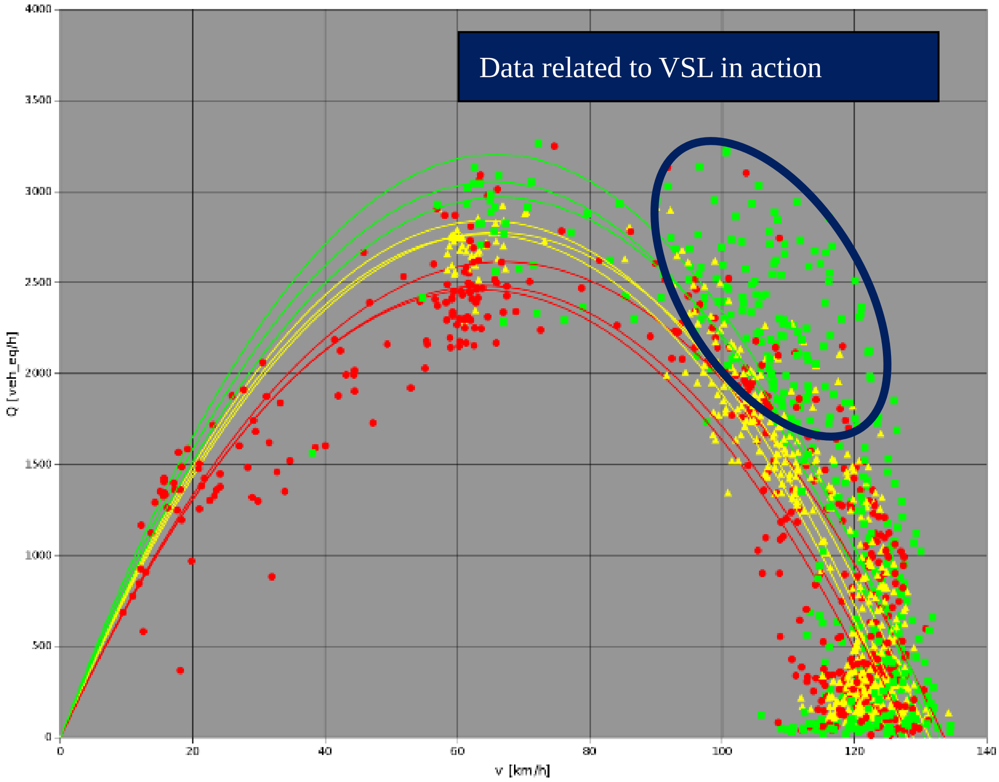

Figure 10 – Empirical traffic fundamental curves (capacity vs. speed) based on traffic measurements at km 156+ 600 related to days of application of VSL for traffic control purposes.

3. “Stick and carrot” policy enforcement

First promising empirical results are leading project partners to study a “stick and carrot” approach [3] for guaranteeing on the long-term period a proper respect of dynamic speed limits, in particular during periods of the year when traffic flows are less intense and their activation for air quality purposes may lead to poor results. Empirical data is showing the presence of two main target groups: (i) a group which is quite ready, for different reasons and motivations, to respect such measures; and (ii) a group which typically does not want to do it, and is also incline not to respect normal speed limits. The second group has to be inevitably addressed by enforcement systems, in particular section control systems that have largely demonstrate to be the most effective ones. The first group can on the other side be motivated by specific incentives, e.g. rewards such as discounts on the toll charges, if they demonstrate to have properly respected the dynamic policies in place on the highway. In order to achieve this, a new “audio-guide” app is under conception (Figure 11). Similarly to other state-of-the art experiments such as Coventry iVMS, this app should not only be able to automatically track the driving patterns, but also to provide, in auditory form in order to minimize the distraction of drivers, added value information such as notification of nearby POIs that can augment the travel experience along the A22 highway. The detailed concept and implementation of this new app concept, which will be included in the current A22 app, is going to start in 2018.

Figure 11 – New concept “app” for the positive engagement of road users.

4. Conclusions and next test phases development

The paper presents a first insight about the empirical results associated to the first test phase organized in the scope of the EU LIFE project “BrennerLEC, which clearly highlight the positive outcomes on traffic fluency and air quality conditions of VSL applied on an alpine highway. These results are calibrating the organization of test sessions during the second test phase, which will last until December 2019. This second phase will be carried out on the entire test stretches, thanks to a new

VMS infrastructure recently installed in the test stretches. Most of them are installed in the BLEC-AQ area, which is currently suffering of poor dynamic signage. VMSs chosen are an innovative product by supplier Aesys, working with solar power only (Figure 12).

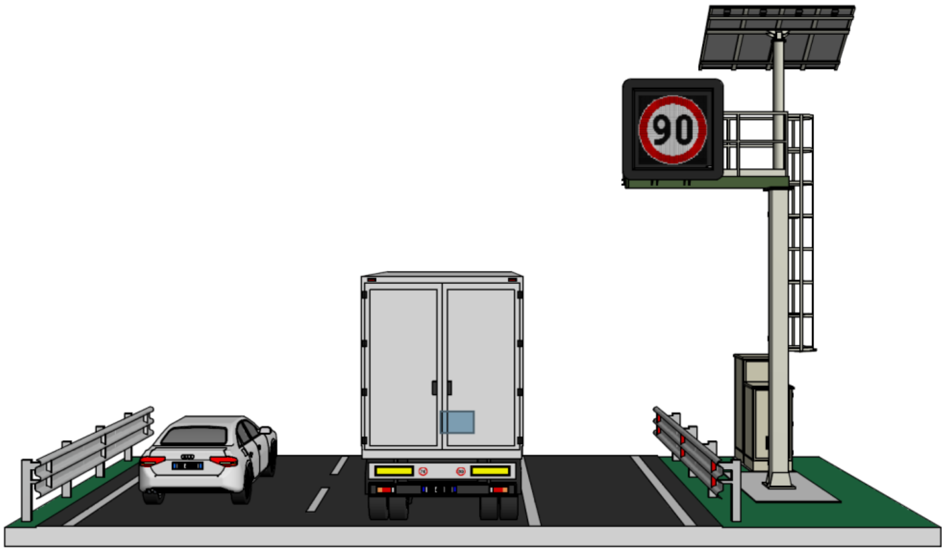

Figure 12 – New VMSs to be used for the successive test sessions on the A22 highway.

In parallel, project partners are working on the development of the ITS architecture, based on the one developed in the scope of the LIFE INTEGREEN project [4]. This architecture will support in the final stage of the project support the activities of TMC operators by means of a Decision Support System (DSS). The DSS will automatically suggest the activation of the dynamic policies proposed on top of all relevant raw data collected and short-term forecasts of traffic and air quality conditions. The suggestion will be calibrated on top of quantitative triggers, e.g. the forecasted exceedance of air quality conditions in correspondence of certain target points near the road or the forecasted entrance in instable traffic conditions.

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