Paper number ITS-TP-1846

About the combination of advanced logics for dynamic VSL activation: an integrated tool to improve traffic flows, control emissions and reduce air pollution

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Abstract

This paper presents the first advanced “environmental traffic management” logics that have been developed in the scope of the EU LIFE “BrennerLEC” project [1]-[2] and that will be tested on the Italian A22 (Brennero – Modena) highway. More specifically, these logics are intended to suggest the operators of the A22 Traffic Management Centre (TMC) on a real-time basis when and where a variable speed limit (VSL) has to be activated in order to cope with increasing traffic flows and/or poorer air quality levels. The novelty of the proposed solution is that for the first time an integrated approach is proposed, targeting the ambition to both bring the highway to its full capacity potential and to control the pollution generated by vehicles. The added value of forecasting components is also presented and discussed. These logics are under implementation and will start to be empirically tested in the first months of 2019.

Keywords:

Environmental traffic management, VSL, triggers, forecasts, air quality.

1. Introduction

The positive effects related to the application of VSL on highways are documented in plenty of theoretical and practical evidences. A comprehensive overview of such benefits can be found for example in [3]. From an environmental point of view, such effects are primarily related to the behaviour of the NOx emission curves of diesel cars. As graphically illustrated in Figure 1, NOx emissions of passenger cars are significantly different if the travelling speed is reduced from 130 [km/h] to 110 [km/h] : according to today’s available emission factors provided by COPERT [4], the reduction of NOx emissions for a EURO 5 diesel car is in the order of 30%. The activation of a VSL has therefore the effect of significantly reducing the emissions of these pollutants from this category of vehicles, with positive consequences also on the average roadside air pollution concentrations. It has to be underlined that this category of vehicles is typically a remarkable component of the overall highway traffic; according to a recent study carried out on the A22 highway, 76% of all circulating vehicles is diesel-fueled and 70% of the vehicles are passenger cars [5].

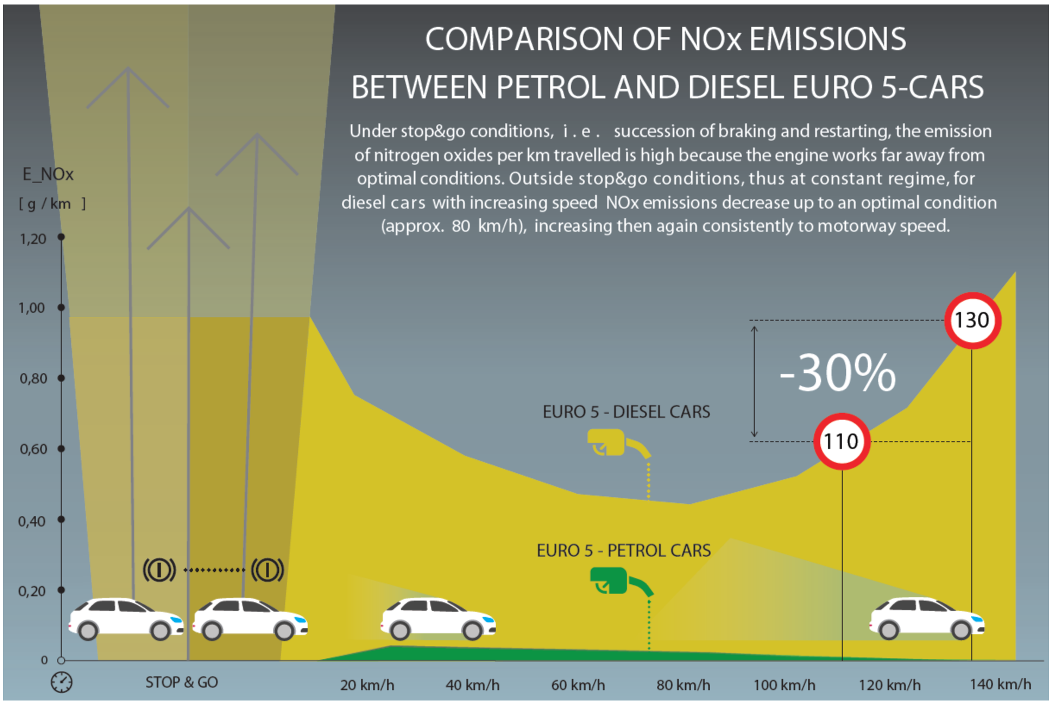

Figure 1 – Qualitative NOx emission profile of a EURO 5 diesel / petrol car.

From a traffic point of view, the benefits of VSL can be understood if fundamental traffic diagrams are considered. In Figure 2 the theoretical speed-flow diagram empirically calculated for a two-lanes stretch under exam of the A22 highway is illustrated. This calculation is obtained in condition of absence of any speed conditioning and therefore has to be considered as a theoretical reference for the starting situation in which VSL are not applied. The diagram indicates that in this theoretical condition the maximum capacity of the carriageway is obtained (about 3.500 equivalent [vehicles / hour]) with all vehicles driving at a constant speed of about 80 [km/h]. In case of controlled traffic by means of VSL, it is possible to shift this optimal reference point to an improved situation of equilibrium, i.e. at increased flow and speed values. This is due to the effect of accompanying traffic to its natural optimal stabilization point and of forcing vehicles to reduce their relative speed differences, which determines an improvement of the homogeneity degree of traffic flows and as a consequence of the safety levels of the road. This improved situation of equilibrium means for drivers a reduction in travel times and for highway operators an improvement of the highway throughput.

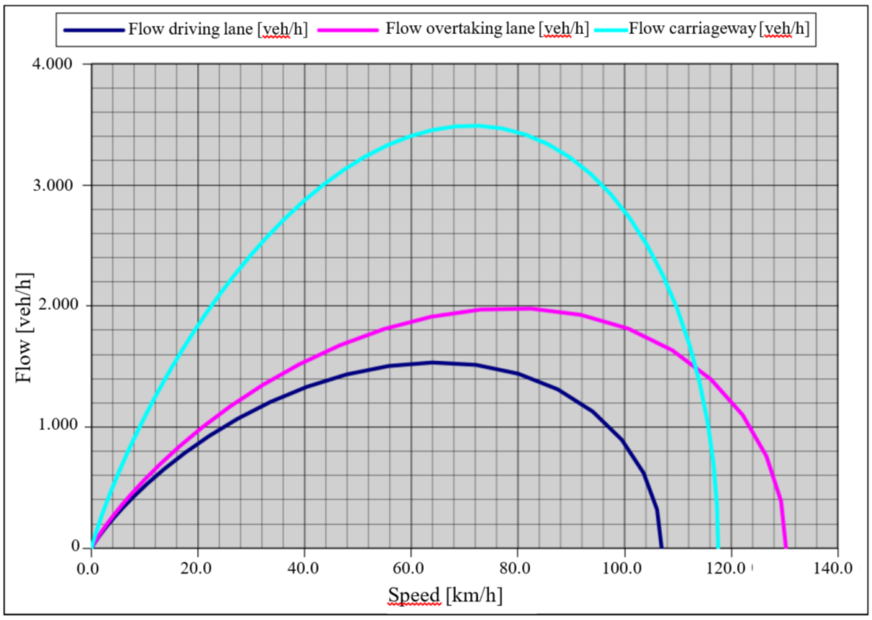

Figure 2 – Theoretical traffic fundamental curve of the A22 test stretch [6].

2. Air quality related logics

2.1 *Optimization potential analysis based on real-life observations*

In the scope of the LIFE BrennerLEC project a first experimental campaign has been completed in order to empirically confirm the potential benefits of VSL on the air quality concentrations at the roadside of the highway. As documented in [2], with average speed reductions of about 15 [km/h] nitrogen oxides roadside concentrations have been reduced of about 10%. Further analyses have revealed how such reductions are correlated with traffic volumes and the conditions of atmospheric stability. The most relevant results are presented in Table 1, and are expressed in terms of difference between the concentrations of NO (expressed in [$\mu g/m^3$]) measured in a point without VSL applied (at km 107+800 of the highway) and in a point with VSL applied (at km 103+700). The hours of tests with active VSL used in this analysis are filtered according to different criteria that are considered favourable in order to effectively verify the target impacts. For more details, please refer to [2]. Please note that for some conditions no statistically representative datasets are available and therefore results are not reported.

Class	$\Gamma \geq 5$	$-5 \leq \Gamma < 5$	$\Gamma < -5$
$N < 500$	-	1.1	4.5
$500 \leq N < 1.000$	-	2.5	11.2
$1.000 \leq N < 1.500$	1.5	11.4	21.3
$1.500 \leq N < 2.000$	10.5	13.2	26.5
$2.000 \leq N < 2.500$	18.6	18.9	-
$2.500 \leq N < 3.000$	13.9	9.0	-
$N \geq 3.000$	7.7	10.6	-

Table 1 – Correlation between reduction of NO concentrations, traffic volumes and atmospheric stability.

The concentrations differences are classified according to two parameters: (i) N, i.e. the total number of light vehicles transiting on both carriageways, expressed in [vehicles / hour]; and (ii) Γ, i.e. the vertical air temperature gradient in the atmospheric layers closest to the ground, expressed in [°C/km], as difference between the air temperature measured at the heights of 0 and 50 [m]. The latter parameter is an indicator of the atmospheric stability, with negative values indicating a situation of thermal inversion. The empirical results confirm that the maximum gain is obtained with intense traffic flows and conditions of thermal inversion, which are the less favourable ones for the dispersion of the pollutants in the atmosphere. It is important to underline that when traffic flows exceed a certain threshold, the speeds are naturally reduced because of traffic conditioning and therefore site-specific differences are smoothened and environmental benefits less evident. This analysis gives therefore a quantitative idea of the theoretical best trade-off between VSL activation and environmental benefits that can be achieved: the estimation is that if VSL would be activated only in the most favourable conditions (highlighted in green, equivalent to 45% of the total hours) the reduction of the concentrations of NO would be the 75% of the reduction that would be obtained with permanent speed limits reduction.

2.2 *Proposed initial logics for triggering VSL*

The results of this analysis have provided a decisive support in consolidating the details of the logics and workflows for triggering VSL in a semi-automatic way. At present, indeed, it is foreseen to give at disposal to the operators of the A22 TMC a Decision Support System (DSS), at least in a first phase, suggesting them for each elementary road stretch (i) if a VSL has to be activated; (ii) and which dynamic speed limit should be applied. The proposed workflow is summarized in Figure 3 and is characterized by the following components:

- **Environmental targets & objectives setting**: defines reference concentrations of NO_2 in correspondence of a specific target point at a certain distance from the highway. Different average monthly concentrations are defined so to guarantee the desired annual average and to take advantage of VSL in all periods of the year. It is expected e.g. to set higher concentrations in winter and lower concentrations in summer. Target concentrations are updated on a monthly basis on the base of the measurements collected by the air quality monitoring system.
- **Meteorological and air quality forecasting chain**: estimates the meteorological conditions and the level of pollution concentrations based on the expected traffic volumes and patterns for the following day. The forecasts are calculated as a function of different data input streams, in particular the traffic / meteorological / air quality monitoring network.
- **Traffic thresholds settings update**: based on the outputs of the previous components, and in particular of the daily meteorological / air quality forecasting chain, reference traffic thresholds for the dynamic activation of VSL are updated on a daily basis. In particular, in case of thermal inversion conditions, such thresholds are lowered.

- **VSL activation suggestion**: the suggestion of activating a VSL is therefore based on the real-time measurements of traffic according to a "state-machine" concept, as better described in the next chapter. Air quality and meteorological measured data are also taken into account to confirm the validity of the available forecasts: if not, traffic thresholds are modified on-the-fly according to the real measured conditions.

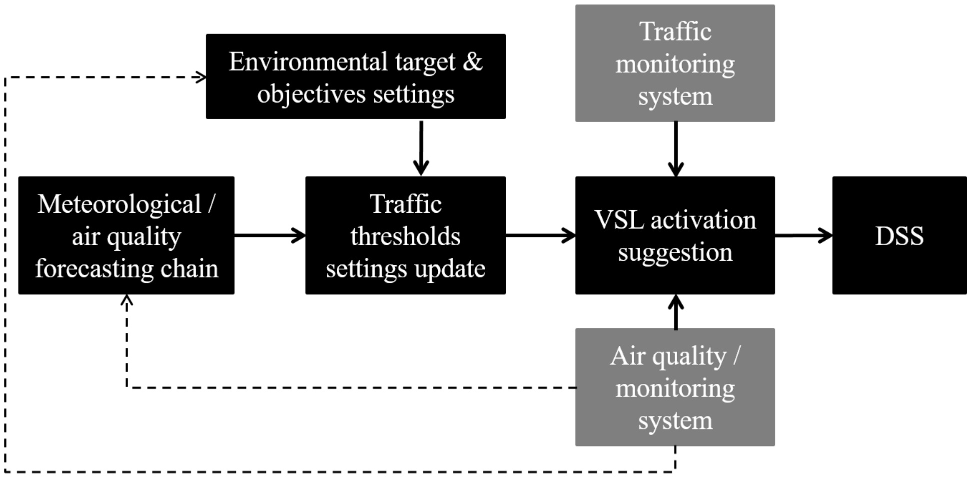

Figure 3 – Proposed logic for the activation of VSL for the minimization of the environmental impact.

Please note that so designed the system could work only with the real-time chain (so called "reactive mode"), by considering reference static traffic thresholds that could be updated e.g. on a monthly basis, or only with the forecasting chain by just considering the suggestion received by this modelling chain. The combination of these two approaches is expected to give the best possible results in terms of compromise between duration of active VSL and obtained reduction of pollutants' concentrations.

3. Traffic related logics

3.1 *Initial insights based on real-life observations*

In parallel to the initial investigations focused on the impacts of VSL on the roadside concentrations of nitrogen dioxide, an additional experimental campaign has been carried out in order to get first insights on the potential added value of the application of reduced VSL in terms of highway capacity, when traffic volumes significantly increase. For a detailed description of this first test phase please refer to [2]. The following plots present two typical situations that have been observed: one in which due to a missed / delayed activation of a reduced VSL vehicles' speeds have collapsed, causing stop&go phenomena to occur (Figure 4); and one in which VSL has been correctly adapted in time according to increasing traffic patterns, with the effect of avoiding any traffic jam and maintaining a desirable stabilization of traffic flows (Figure 5).

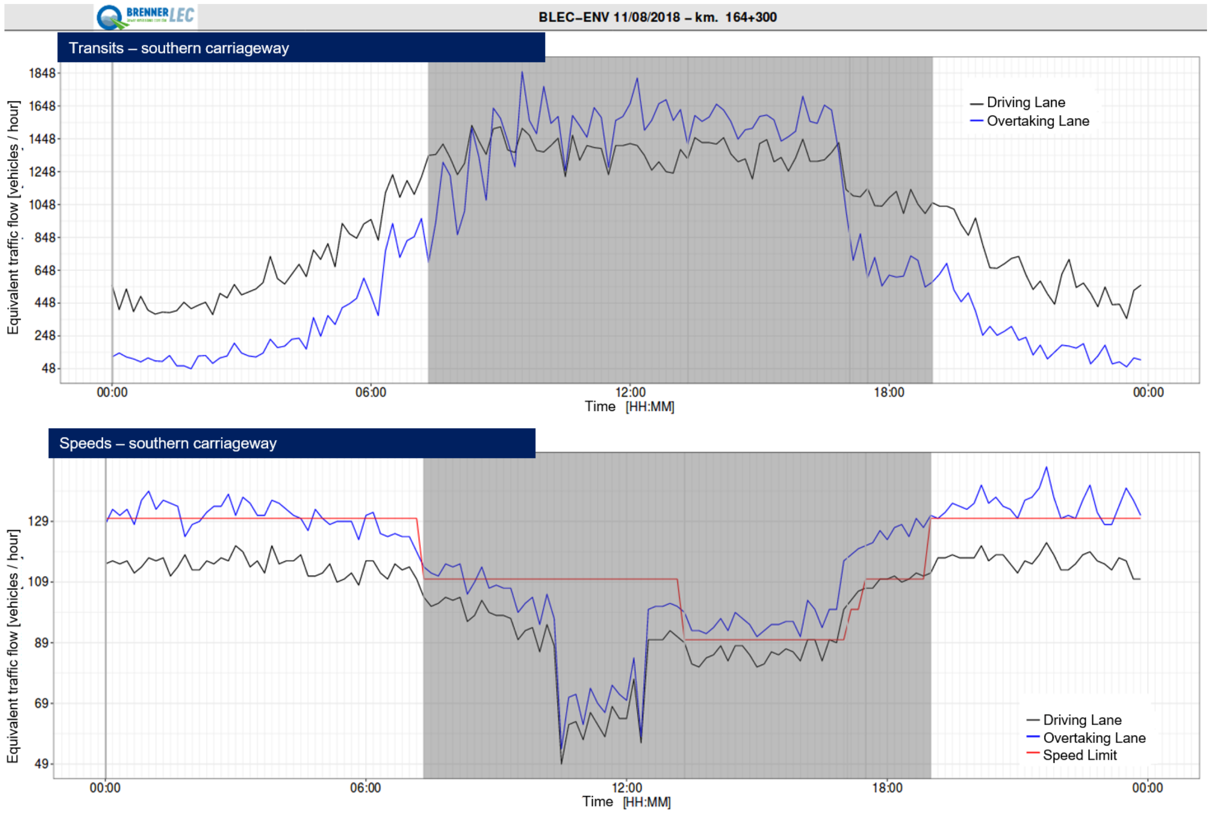

Figure 4 – Traffic details related to a failed application of VSL to increase traffic capacity.

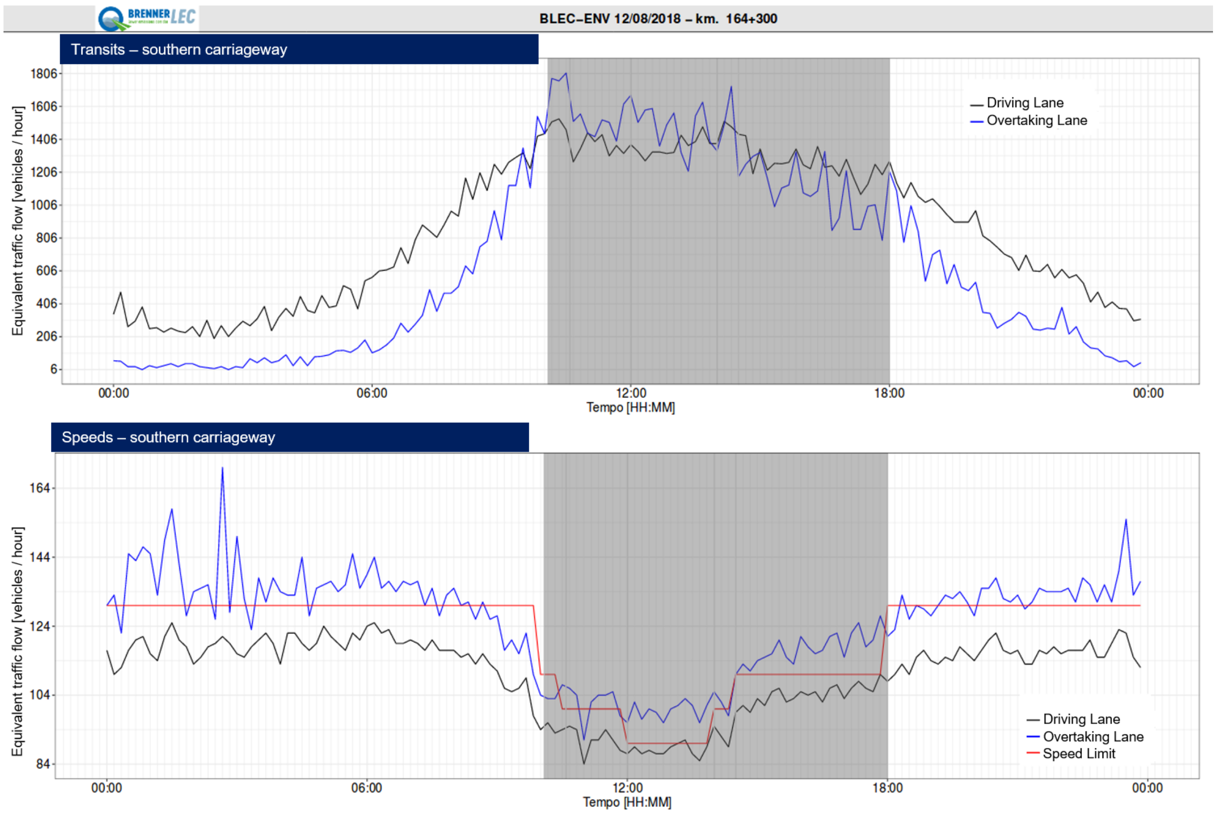

Figure 5 – Traffic details related to a successful application of VSL to increase traffic capacity.

More in detail, in the first case we see that the dynamical speed limit wasn't adapted quickly enough to the vehicle flow variation, determining a collapse in speed; only a further (delayed) reduction was able to partially recover the traffic condition. Despite the difficulties in comparing different traffic conditions, which can be affected by different boundary situations, and despite the limited number of empirical evidences collected so far, the main indication obtained by this first empirical experience is that the desirable modality of managing such a critical traffic condition is to gradually but continuously adapt VSL according to varying traffic conditions, by avoiding any sharp variation of VSL (e.g. from 110 [km/h] to 90 [km/h]).

3.2 *Proposed initial logics for triggering VSL*

The results of this analysis have led to an initial definition of the way VSL can be timely activated according to real-time traffic conditions. In particular, a "state-machine" concept is introduced: the passage from one state to another is based on the exceedance of certain thresholds for a certain minimum interval of time, in particular the number of vehicles and the average and variance of the vehicular speeds. Two aspects are important to be underlined: (i) the possibility of one state to pass only to a state associated to the nearest upper / lower value of VSL; and (ii) the different threshold values that are proposed for a state change in the two opposite directions. A first draft of the proposed machine can be found in Figure 6. Thresholds and considered parameters are still indicative and will be fine-tuned according to future empirical evidences. Please note that the state change between the condition "90 [km/h]" to "130 [km/h]" is only artificial, since it is associated with the opportunity not to display any VSL when traffic jam situations occur. Specific tests are going to be organized in the next months in order to check if the maintenance of such messages even in such conditions can lead to increased flows' stabilization when speeds start again to increase. It is also under evaluation the possibility to apply VSL even down to 80 [km/h]. Please note that the VSL of 120 [km/h] is not foreseen in the Italian traffic laws and it is therefore neglected.

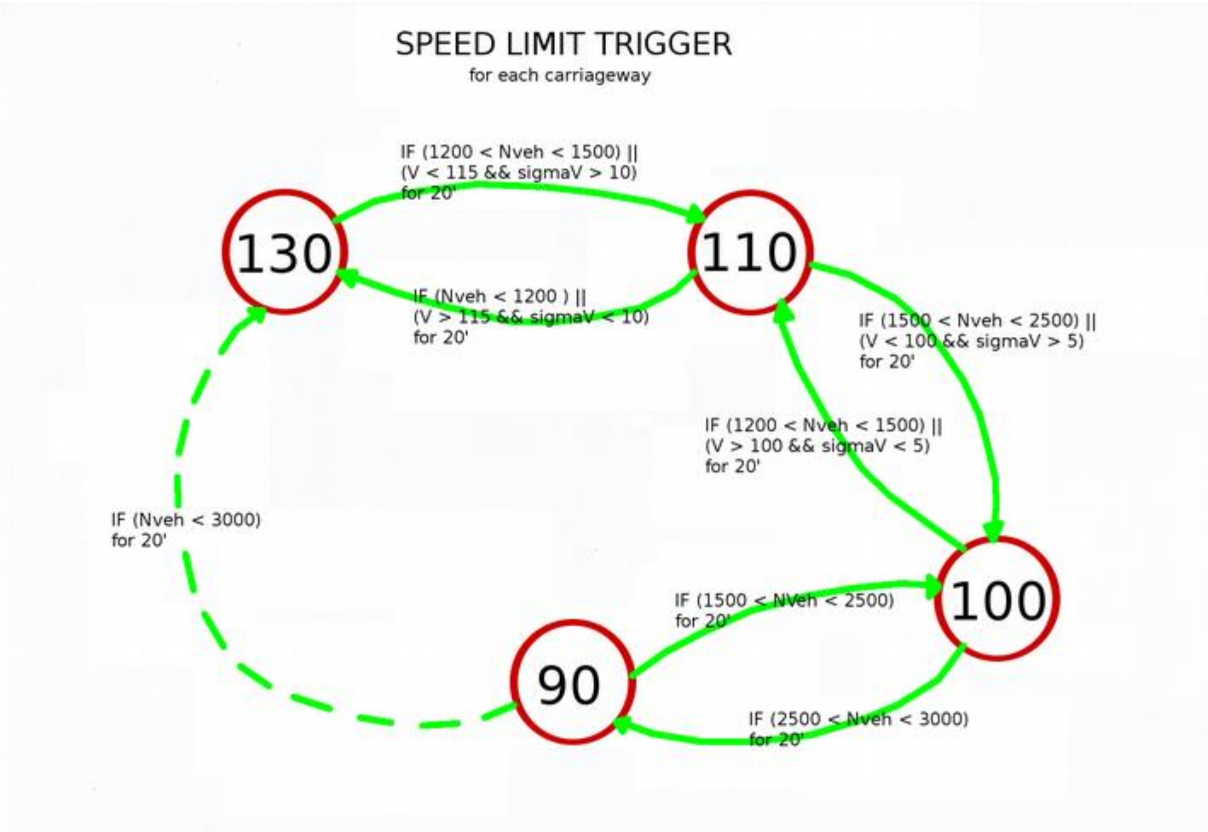

Figure 6 – First draft of the "state-machine" to regulate VSL according to real-time traffic.

4. Combination of air quality and traffic related logics

But what about optimally managing traffic and at the same time roadside air quality concentrations through VSL? Our proposal of combination of the above presented logics is schematically summarized in Figure 7.

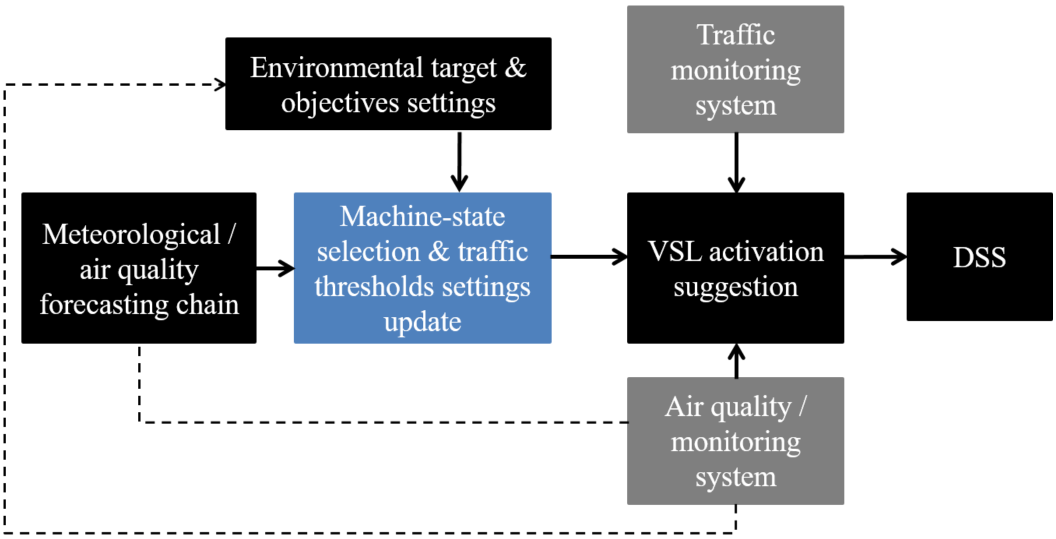

Figure 7 – Combined logic for the activation of VSL for both traffic / air quality application scenarios.

The concept is very similar to the one introduced for the VSL activation due to air quality, but with a conceptual and decisive improvement: the idea to not just adapt traffic thresholds according to the environmental targets set and the outputs of the forecasting chain, but also to select the most appropriate state-machine, as summarized in Table 2. In this hypothesis the state “80 [km/h]” has also been considered.

Atmospheric stability class	State-machine name	Logic
$\Gamma \geq 5$	**“Full-traffic”**	130 ↔ 110 ↔ 100↔ 90↔ 80
$-5 \leq \Gamma < 5$	**“Mix traffic / air quality”**	130 ↔ 110 ↔ 100↔ 90↔ 80
$\Gamma < -5$	**“Nearly full-air quality”**	130 ↔ 110 ↔ 100↔ 90↔ 80

Table 2 – Relation between atmospheric stability class and related state machine.

The basic idea is that in case of stable atmospheric conditions (therefore favourable to pollutants accumulation) the application of VSL is driven by air quality criteria (red arrows), up to a situation of traffic flows in which traffic-related criteria (yellow criteria) are started to be considered again (“nearly full-air quality” state machine). On the contrary, if atmospheric conditions are favourable to pollutants dispersion, traffic criteria are dominating (“full-traffic” state machine). In an intermediate situation, a mix between air quality and traffic criteria are used, i.e. VSL applied for environmental purposes can be applied only to a certain reference state, e.g. 100 [km/h] (“mix traffic / air quality” state machine). It is important to underline that in the same day different atmospheric conditions can be observed, therefore a dynamic change between state machines should be taken into account.

5. Conclusions and next steps

The paper has presented the current approaches that are still under investigation within the LIFE project BrennerLEC aiming at defining how VSL can be dynamically activated on the Italian A22 highway in order to reduce the roadside air pollutant concentrations and improve the traffic capacity. The novelty of the proposed approaches is the combination logic, which is proposed to find an optimal balance between the two different application scenarios.

In the first months of 2019 it is expected to start to empirically test and refine the proposed logics. More in particular, the first ones that will be investigated will be the “full-traffic” state machine, which is going to be applied on the entire BLEC-ENV test stretch, from Bolzano North to Rovereto South [1]. Since the entire test stretch is quite long (about 90 [km]) and can be characterized by different traffic conditions, three sub-stretches of about 30 [km] each are going to be considered. Each sub-stretch will be managed independently, by applying a VSL according to the traffic measurements collected by the available traffic detection points. Since these points are in general multiple, a VSL is going to be activated if threshold conditions are fulfilled in at least one of the observation points. Particular attention has to be put at the boundaries of the sub-stretches, in order to ensure a smooth spatial transition between zones with different VSLs. Differently from the past, in which test days were previously predetermined according to expected traffic volumes, in this new test phase VSL could be activated anytime, if observed conditions recommend to do so.

At present, the activation of VSL, according to air quality criteria, is limited to a small portion of the BLEC-ENV road stretch, called BLEC-AQ, with an extension of about 20 [km], located between the toll gates of Egna / Ora and S. Michele [1]. During the last months project partners have decided for a small extension of the test stretch, so that the BLEC-AQ stretch can have a better overlapping with one of the BLEC-ENV sub-stretches, in particular the central one. Additional Variable Message Signs (VMS) will be furthermore installed in this road stretch so to allow the possibility to test the proposed combined logics also in the north carriageway of the central BLEC-ENV sub-stretch and to make a more complete assessment of its empirical application. Application of the air quality criteria for the VSL activation is scheduled for the second half of 2019, while the launch of the enhanced combined logics empowered by the forecasting chain is going to take place at the beginning of 2020.

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