EVALUATION OF DYNAMIC SPEED CONTROL ON THE VENICE - MESTRE BELTWAY

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ABSTRACT

One of the most critical bottlenecks of the TERN is the A4 motorway stretch in the area of Venice - Mestre (IT). The A4 motorway stretch in the urban area of Venice - Mestre is daily used by 170.000 vehicles.

In 2003 was activated the T3 system for the use of hard shoulders as rush hour lanes. The T3 system is based on a set of 25 gantries with variable lane signs installed along the 9 km long A4 stretch. When the traffic reach a certain level, hard shoulders are open to traffic flows providing an extra capacity.

The T3 system includes a dynamic speed control functionality. Variable speed limits may be applied for each lane of the beltway. Speed limits are automatically defined according to the current traffic measurements. After a period of detailed calibration, the dynamic speed control is now fully in operation. It operates every day from 5a.m to 10p.m.

The presented paper will report on the evaluation of the impact on mobility and of the effectiveness of the system. The analysis will follow the indication of the Evaluation Expert Group Guidelines and the objectives of the EASYWAY Project that are:

- Impact on road safety
- Impact on congestion;
- Impact on environment

Furthermore some more specific areas have been investigated:

- Drivers’ response to dynamic speed limit variation
- Effects on traffic flow conditions

1. DESCRIPTION OF THE PROBLEM

1.1 SITE

The Società delle Autostrade di Venezia e Padova S.p.A. manages three main sections of the motorway network (see Figure 1), including the Mestre Beltway, which is the subject of the present study:

- The Venezia – Padova motorway section;

- The Mestre Beltway, which is connected to ordinary roads. The Concessionary Society Autostrade di Venezia e Padova manages the section of the Beltway between km 258 + 900 and km 265 + 800; the remaining section (between km 265 + 800 and km 268 + 500) is managed by the Concessionary Society Autovie Venete S.p.a.;
- The junction with the airport Marco Polo, which joins the Beltway and the motorway A27 Venezia – Belluno with the state road S.S.14 *Triestina*.

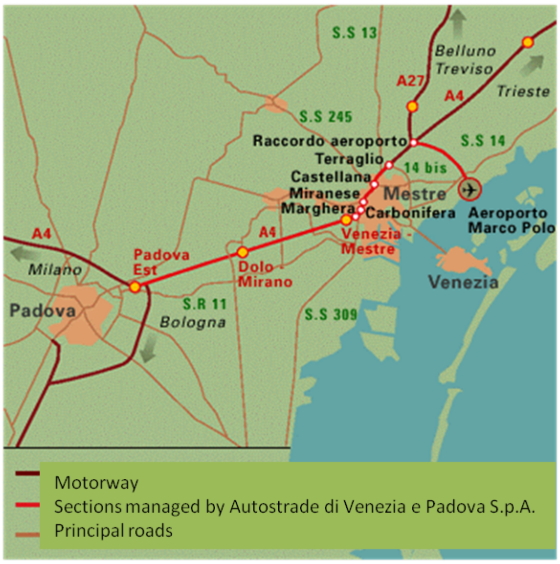

Figure 1 - Map of the motorway VE-PD.

The area of Mestre represents the main narrow neck of the network in the north-eastern Italian area.

The high levels of traffic travelling on the Beltway have caused for many years a critical situation with slowdowns, traffic jams and queues for most daytime. Another negative factor is the presence of a great number of heavy vehicles, representing a high percentage of the overall traffic on this network.

By way of example, data collected at the end of 2008 showed an average traffic demand on the Beltway of over 165.000 users per day, with 4.000 v/h per direction during rush hours (and peaks of over 5.000 vehic/h) and a percentage of heavy traffic of 27%.

Considering the problems of congestion stated above, and in order to optimize the use of the Mestre Beltway, the following significant interventions were implemented in the last decade:

- in 2000 the system MARCO (*Motorway Access Regulation and Control*) was launched. It is based on *ramp metering* (access control) in order to optimize traffic conditions on the Beltway. It allowed to register a 7% increase in the average speed during rush hours;
- since 2003 the project T3 has been implemented. It is based on the use of the emergency lane under heavy traffic conditions to increase, if necessary, the capacity of the Beltway; this is possible by changing the number of lanes that can be used. Indications of these changes are given by variable message systems. This system (activated on 14th April 2003 for the westbound carriageway, on 26th June 2003 for the eastbound carriageway) had significant advantages in terms of congestion and safety. The length of queues registered a considerable decrease, the average speed increased by over 11% and accidents diminished by 60%;

- the regulation of speed limits based on traffic conditions on the network, subject of this paper. The system is currently active every day from 5.00 a.m. to 10.00 p.m. and it uses the same information systems as the T3 system, e.g. VMS; it can therefore also be considered as a part and development of the T3 system.

1.2 OBJECTIVES

The mainly objectives pursued are:

- Traffic flow: improving traffic conditions by means of an optimal use of the infrastructural resources available, increasing the capacity of the Beltway system whenever necessary and thus obtaining:
  - A more homogeneous and higher speed and therefore a shorter journey time;
  - Infrastructure capacity to better get traffic flows moving along the section concerned, in particular during rush hours, with a reduction of the unsatisfied demand share.
- Safety:
  - Ensuring that speed limits indicated by VMS are respected;
  - Decreasing accidents caused by micro-collisions due to congestion and “stop & go” by regularizing traffic flows.
- Environment: indirectly reducing the emissions of polluting substances, vehicles flows being equal, by improving traffic fluidity and decreasing congestion that causes particularly polluting driving cycles.

In particular, the speed control strategy pursues the following technical objectives:

- Defining the speed to show on the VMS installed on the Beltway and on the motorway. This strategy is based on the principle of slowing down flows so that vehicles will approach the “critical” section, i.e. the one with the highest density, only when they can pass without slowing down because of queues;
- Trying to prevent critical densities.

1.3 SYSTEMS AND TECHNOLOGIES ADOPTED

The speed control strategy consists in a specific algorithm, which is part of the more general strategy of lane management using the infrastructural system of the T3 project.

It dynamically defines the recommended speed on each section based on updated and properly filtered traffic conditions. Under consideration of the events, it implements the principle of “protection of the area affected by an event (sensitive area)”, thus producing the indications on the recommended speed and the use of lanes in line with this principle.

The resulting messages with their priorities are then managed by the conflict-solving module, eventually producing the final configuration of messages to send to the front ends of the variable message system.

2. EVALUATION OF THE SYSTEM

2.1 OBJECTIVES OF THE EVALUATION

The study aims at evaluating the impacts of the Dynamic Speed Control implemented on the Mestre Beltway, which is considered as a means to further optimize traffic flows on a road where congestion frequently occurs.

2.1.1 **Description of general indicators**

Analyses were carried out that proved useful to understand traffic conditions on the whole Beltway, taking into consideration the following aspects:

- Time analysis:
  - Flow
  - Speed
  - Density
- Space analysis:
  - Flow
  - Speed
  - Density
- Observance of limits:
  - Comparison between given and measured speed
  - Observance of limits per lane
  - Average speed at limits

2.2 METHODS

The method adopted is based on the combined use of traffic/speed/density data collected and on data recorded by the Dynamic Speed Control on the speed limits shown.

The final objective of the setting-up of this method was the possibility to compare two different time sets, having traffic characteristics as similar and comparable as possible, with the control system deactivated in the first case, and activated in the second case. This allows to evaluate the impacts of the system on by comparing data on the two different periods.

2.2.1 **Data aggregation**

The analysis of such a complex phenomenon as the circulation of vehicles on an infrastructure requires a high level of abstraction and management of the several dimensions of this phenomenon. In this specific case at least four dimensions can be identified:

- time: analysis of time indicators. The variation of data over time is evaluated;
- longitudinal space: analysis of indicators along the journey direction on the Beltway. The variation of data is evaluated between the several sections of measurement;
- transverse space: analysis of indicators on the carriageway. The variation of data is evaluated between the several lanes: fast, normal and slow;
- classes of vehicles: analysis and comparison of indicators on several classes of vehicles (light and heavy vehicles).

Time

Data on flow and speed were averaged out at a quarter of an hour to provide a higher reliability and avoid excessive fluctuations due to possible mistakes made by instruments. A good time resolution of the phenomenon was however guaranteed even using data collected every quarter instead of every five minutes. Data on both flow [vehicles/hour] and speed [km/hour], collected every five minutes, were averaged out at a quarter of an hour with an arithmetic average.

$$f_{quarter_i}=\frac{f_{interval_1}+f_{interval_2}+f_{interval_3}}{3}$$

Space

The flow and speed thus obtained are then aggregated at carriageway level. Flows were simply summed up:

$$f_{carriageway}=f_{fast}+f_{normal}+f_{slow}$$

Speed was averaged out by measuring it based on flows:

$$v_{carriageway}=\frac{v_{fast}\cdot f_{fast}+v_{normal}\cdot f_{normal}+v_{slow}\cdot f_{slow}}{f_{fast}+f_{normal}+f_{slow}}$$

Class of vehicle

Flows of vehicles belonging to class 1 were then aggregated to vehicles of class 2 based on an equivalence factor that is equal to 2. The equivalent flows therefore result from:

$$f_{eq}=f_{class\ 1}+f_{class\ 2}\cdot 2$$

And the equivalent speed from:

$$v_{eq}=\frac{v_{class\ 1}+v_{class\ 2}\cdot 2}{3}$$

Densities were finally recalculated based on flow and speed data, as data provided are rounded up to the nearest integer, thus resulting scarcely precise.

$$k=\frac{f}{v}$$

2.2.2 **Analysis of traffic data at changes of the system state (on/off)**

The Dynamic Speed Control indicates a target speed according to traffic conditions. The speed given on the variable message system may result from three different procedures:

1. VMS indicates the standard speed that is not calculated by the Dynamic Speed Control;
2. VMS indicates the standard speed that is calculated as target speed by the Dynamic Speed Control as no critical situations occur;
3. VMS indicates another speed that is calculated as target speed by the Dynamic Speed Control after critical situations occur.

The speed given therefore results from the state of the Dynamic Speed Control. The nomenclature referring to the several states of the system is as follows.

ON: day when the Dynamic Speed Control is operating, i.e. not deliberately switched off. It can therefore intervene, if necessary, by indicating a different speed from the standard one.

ACTIVATED: time interval when the Speed Control system calculates and indicates a lower speed than the standard one, since congestion is detected on at least one section of the Beltway.

ON

DEACTIVATED: time interval when the Speed Control system, on an ON day, does not intervene since no congestion occurs on any section of the Beltway. The speed given is the standard one.

OFF: day when the Speed Control system is deliberately switched off and so cannot intervene to change the behaviour of the vehicle flow.

All data available and applicable were divided into two groups (days on and off) to make a comparison of the traffic trend with and without the Speed Control system on. In order to make a quantitative analysis of the effects of the Speed Control system on traffic, 2 sets of comparable data must be provided, one when the system is on, the other with the system off, flow characteristics being equal. Flows must follow a trend that is as similar as possible both in terms of total daily traffic flow and of hourly and space trend. This condition was assumed as the Speed Control is supposed to be able to change the distribution of flows over time, favouring or not the transit of vehicles on a section within a given time interval, but without affecting the daily total vehicles passed, if not in the long run. For the analysis of flow data and hourly trends, before and after the Speed Control was implemented (on 17th January), 3 clusters were identified: working, pre-holiday and holiday.

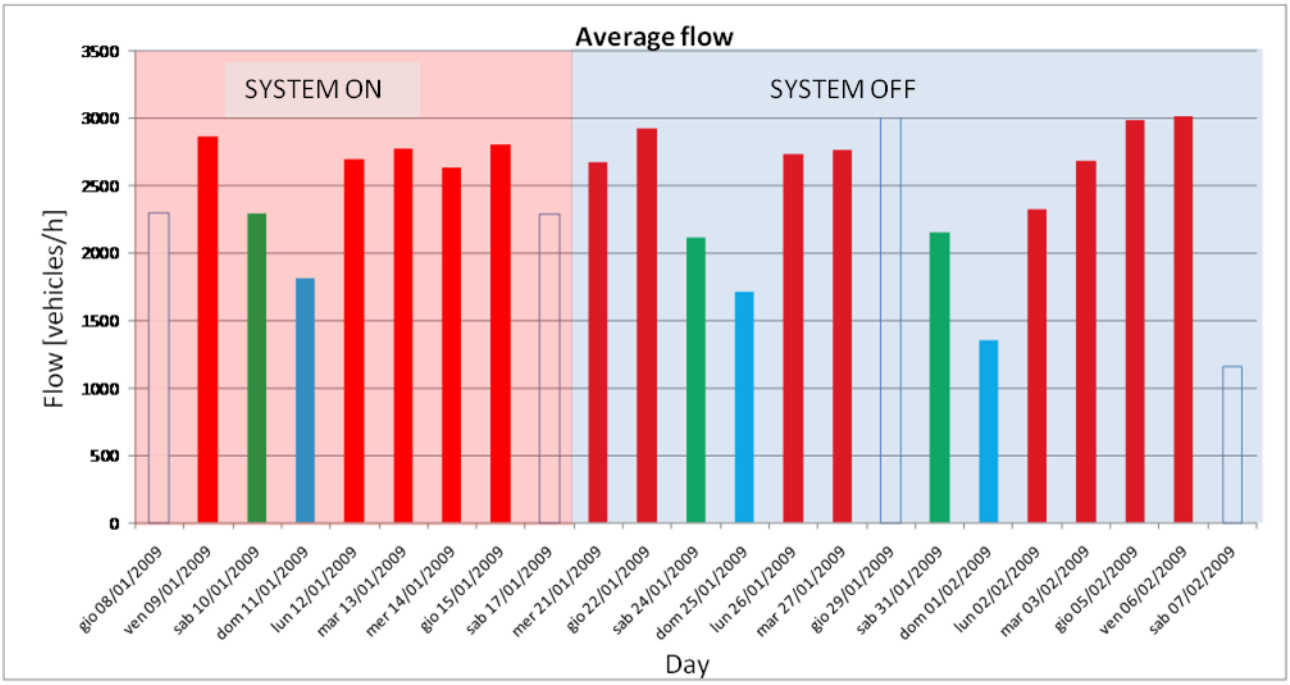

Figure 2 - Choice of days and cluster identification based on the average daily flows per single days.

3. THE IMPACT OF THE PROJECT-RESULTS

3.1 TECHNICAL PERFORMANCE

On the days under consideration the system intervenes properly when congestion exceeds the limits imposed. The algorithms developed and the strategy of intervention of the control system are consistent with the aims it was developed for. It will be possible to maintain and further improve the technical standards of the system by carrying out recurring analyses of traffic data, as well as by adapting the management algorithms to the trend of the transport demand and to variations in the offer system (for example the opening of the Mestre Link and the subsequently new distribution of traffic flows).

3.2 RESULTS

Here follow the main results obtained by evaluating several indicators, such as:

1. speed;
2. density;
3. hours under congestion;
4. standard deviation of speed;
5. observance of speed limits.

3.2.1 **Speed**

Data in Table 1 show a clear improvement in the average journey speed during peaks, from 68,8 to 72,7 km/hour with an increase by 5,73%. The increase is also shown by data on the whole day, with an increase by 3,29% in the average journey speed.

Table 1 - On/off average speed during the several different time intervals (vehicles/hour).

Time interval	***System Off***	***System On***	***Absolute difference***	***% difference***
Whole day	71,1	73,4	2,3	3,29%
Rush hours	69,6	72,0	2,4	3,40%
Peaks	68,8	72,7	3,9	5,73%

By analyzing the average hourly speed at each hour, as shown in Figure 3, an increase in speed results at every hour, except for a substantial stationariness at 7 and 9.

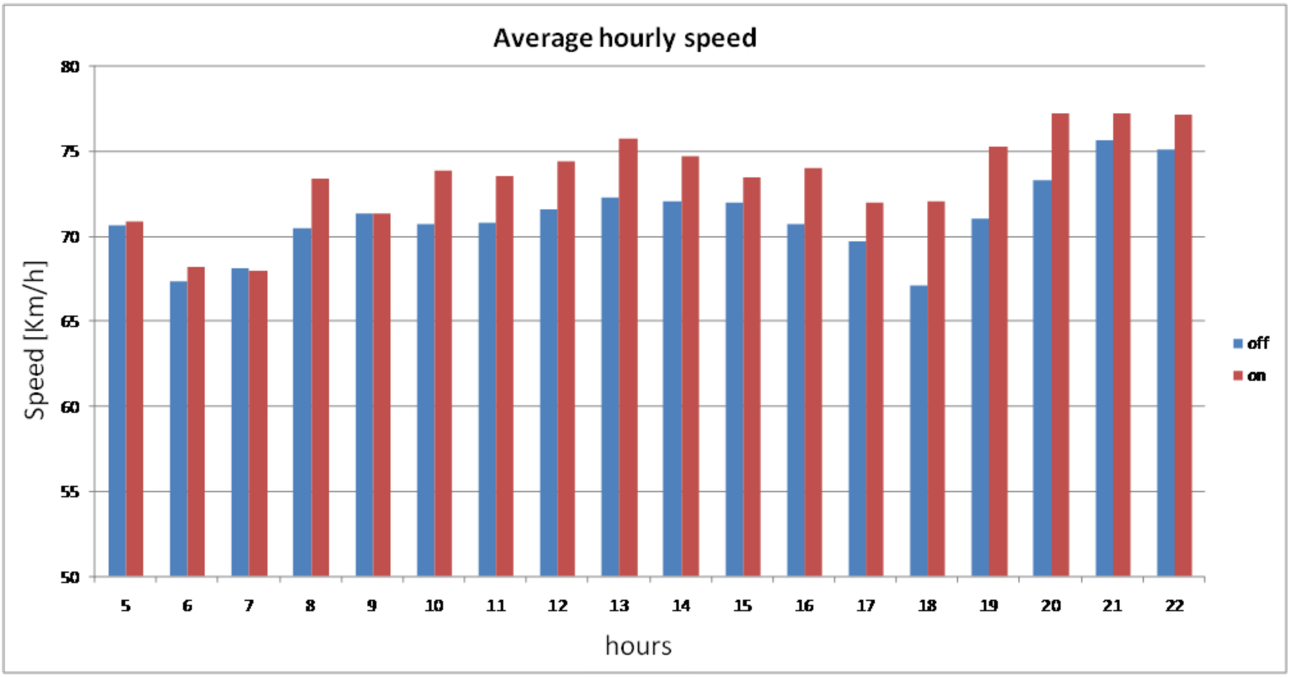

Figure 3 - Average hourly speed based on the state of the system (on/off).

A space analysis of the phenomenon during the time interval with the highest congestion (peaks at 8 and 18) shows an increase in speed on all sections even up to 10%.

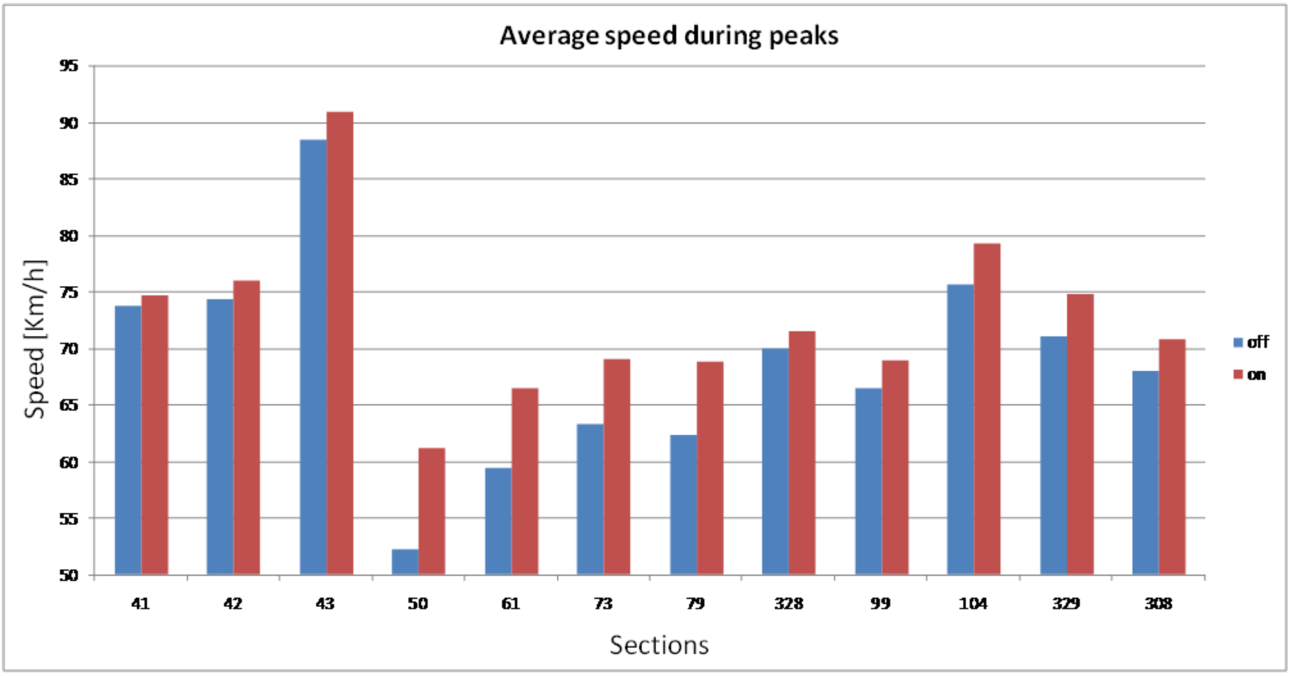

Figure 4 - Average speed during peaks based on the state of the system (on/off) on the several sections under consideration.

By intersecting data on speed reduction with data on flow, the 4 sections (79, 308, 329, 73) with the highest flow during peaks (a higher flow by 4.000 vehicles/hour) show an increase in speed by 7,31%, that is over the average of all sections that, as shown in Table 1, is 5,73%. A sensible increase in the average speed therefore results during the hours and on the sections that are characterized by a higher congestion.

3.2.2 **Density**

Even average densities show a clear improvement, with an average daily decrease by 6,86%, reaching 9,42% during peaks.

Table 2 - On/off average density during the several time intervals (vehicles/km).

Time interval	*System Off*	*System On*	*Absolute difference*	*% difference*
Whole day	41,4	38,5	-2,8	-6,86%
Rush hours	53,0	49,8	-3,2	-5,98%
Peaks	57,9	52,5	-5,5	-9,42%

The analysis of the phenomenon at every hour of the day (Figure 5) shows a reduction of density, therefore a higher fluidity of traffic at every hour (except at 5, which is not significant considering the limited flow value).

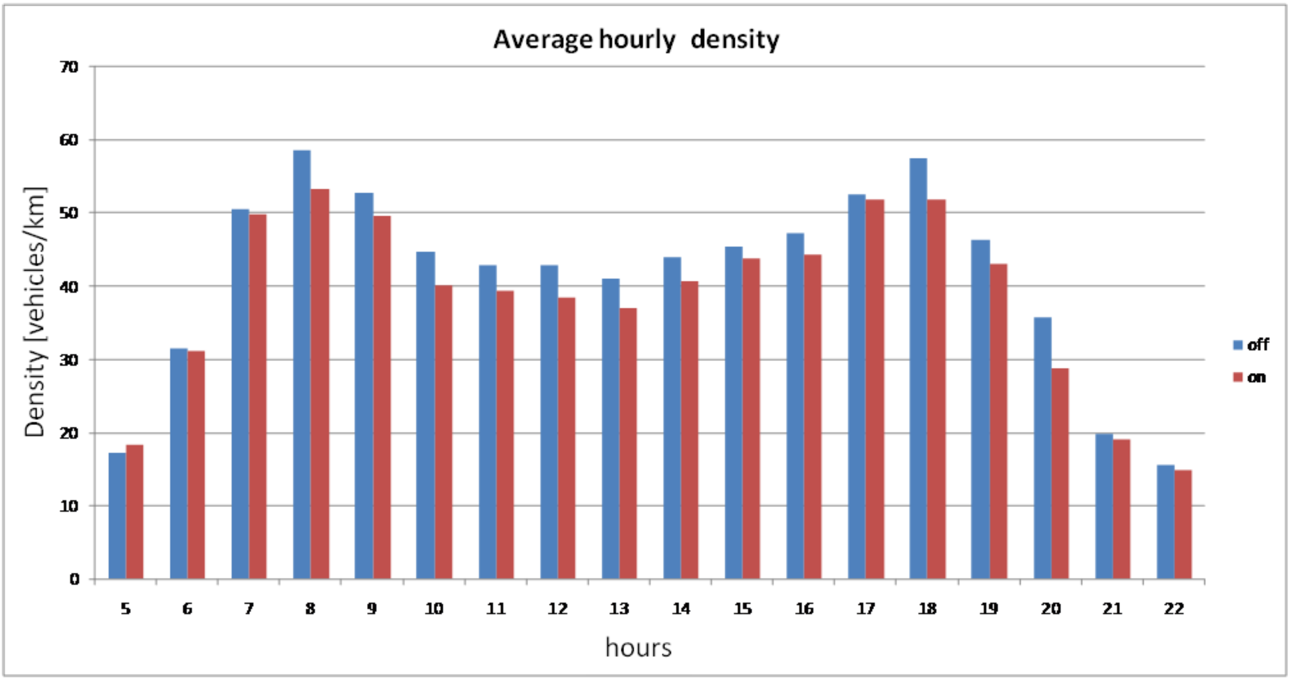

Figure 5 - Average hourly density based on the state of the system (on/off).

A space analysis during peaks, when density decreases by 9,42% (Table 2), shows that density considerably decreases on all sections (except for a slight increase on section 41, which however does not present critical density values), sometimes even over 10%, and in one case reaching 21,90% on section 50.

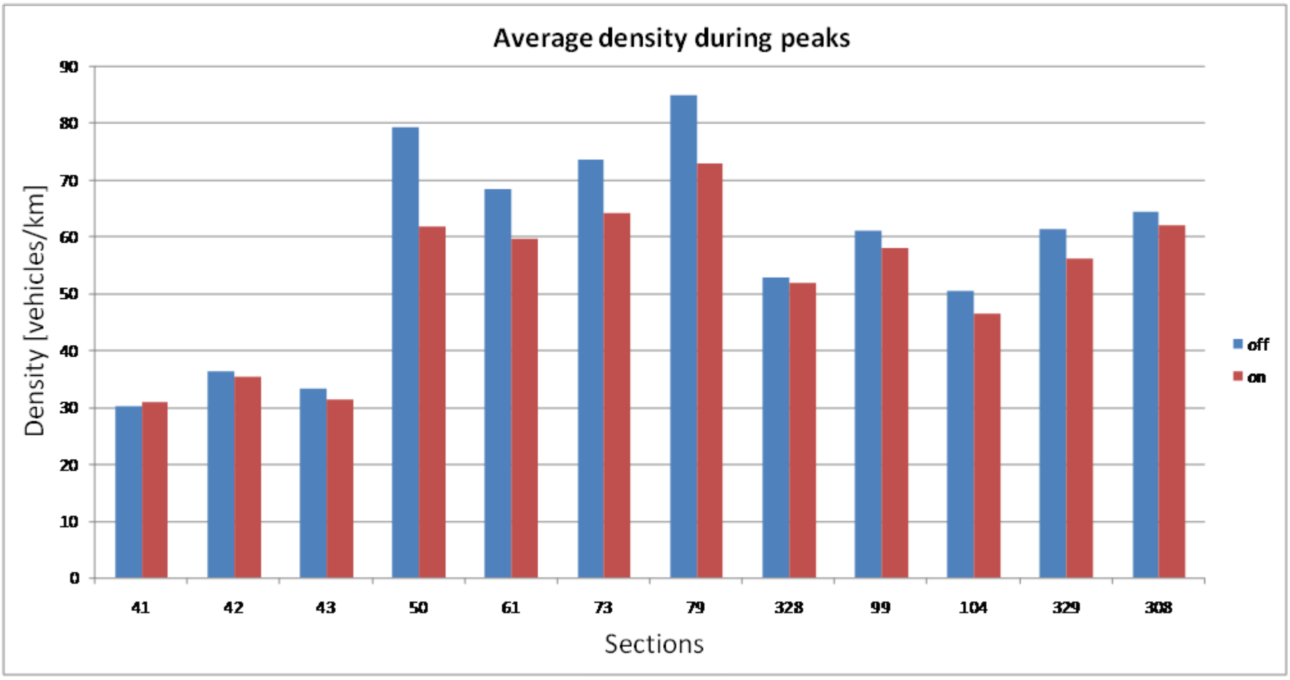

Figure 6 - Average densities during peaks based on the state of the system on the several sections under consideration.

The analysis of the 4 sections having a higher density (79, 50, 73 and 61, with a density of 85, 79, 73, 68 vehicles/km respectively during peaks with the system off) shows an average reduction of density by 15,36%, that is about 6 percentage points higher than the total average of the Beltway. Even considering this indicator, the system proves its effectiveness on the most critical sections.

3.2.3 **Hours under congestion**

An important indicator of traffic trend is the hours spent under congestion, that is those hours when the density value exceeds a given critical threshold. These densities were suggested by the Società delle Autostrade di Venezia e Padova and applied as threshold for the algorithm of the Dynamic Speed Control. If traffic conditions cause a higher density, the Dynamic Speed Control will activate. In order to calculate the hours under congestion on a single lane, the number of quarters was calculated when at least one lane exceeds the threshold.

$$n_i = \sum_{5:00}^{22:00} c_t$$

Where:

- n_i = number of quarters under congestion on section i
- $c_t = \begin{cases} 1 \ if \ (d_{fast} \geq \tilde{d}_{fast}) \ or \ (d_{normal} \geq \tilde{d}_{normal}) or \ (d_{slow} \geq \tilde{d}_{slow}) \\ 0 \ otherwise \end{cases}$

  Where:
  - d_{lane} = density on the fast, normal, slow lane
  - $\tilde{d}_{lane}$ = critical density on the fast, normal, slow lane

The average hours under congestion on the whole Beltway therefore result from the average hours under congestion on single sections.

The following table shows the values of the hours spent over the critical threshold during the several time intervals.

Table 3 - Average hours over the threshold during the several time intervals (hours:minutes).

Time interval	***Total hours***	***System Off***	***System On***	***Absolute difference***	***% difference***
Whole day	17	9:21	7:55	-1:26	-15,24%
Rush hours	6	4:07	3:43	-0:24	-9,46%
Peaks	2	1:45	1:23	-0:22	-21,43%

Data in Table 3 show a clear reduction of the time spent under congestion. For example, before the Dynamic Speed Control was implemented, during the whole day of 17 hours (the analysis refer from 5:00 to 22:00) each section was under congestion for 9 hours and 21 minutes on average, while after the activation of the Dynamic Speed Control congestion decreased to 7 hours and 55 minutes, with an absolute reduction of 1 hour and 26 minutes (- 15,24%). The percentage reduction is even higher during peaks, when the system reduces by 21,43% the time under congestion. A space analysis considering the whole day, see Figure 7, shows a reduction of the hours under congestion on all sections.

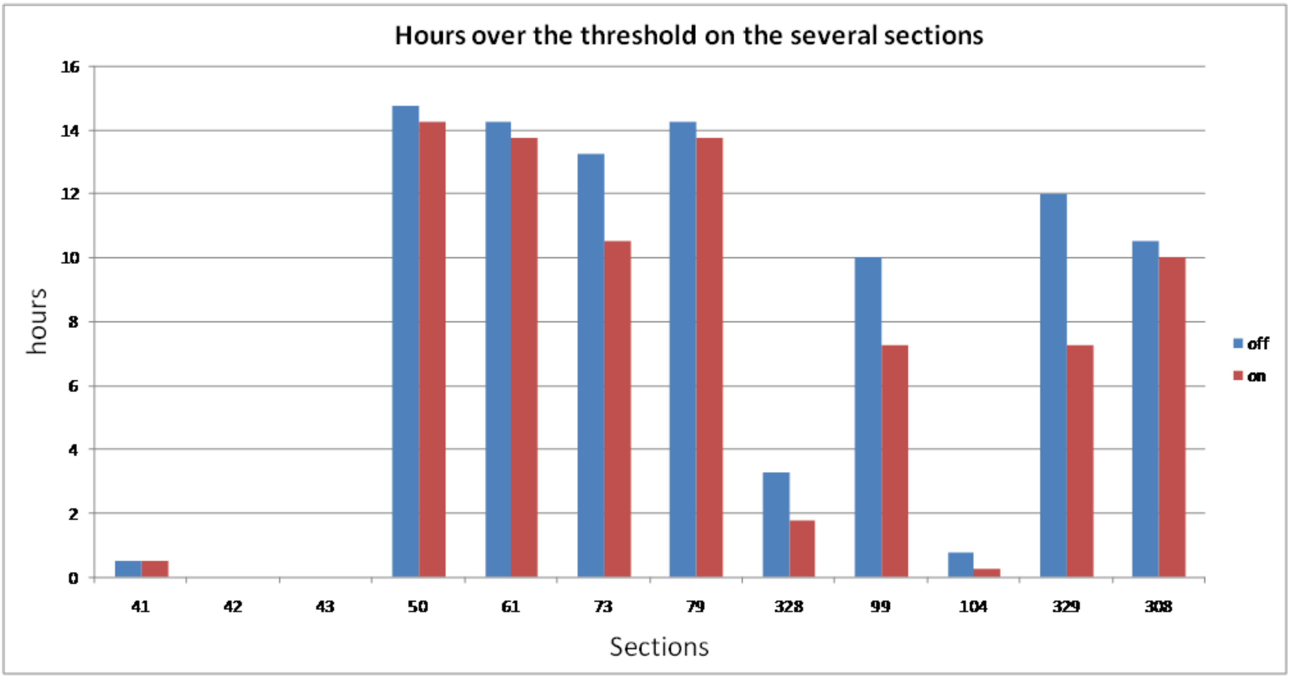

Figure 7 - Average daily hours over the threshold based on the state of the system (on/off) on the several sections under consideration.

3.2.4 **Standard deviation of speed**

A further indicator of traffic trend is the standard deviation of speed or mean square deviation. The standard deviation measures the dispersion of data around the expected value. In particular, if it is calculated for the speed of the several vehicles, it will indicate the level of homogeneity of traffic trend.

$$standard\ deviation_{speed} = \sqrt{\frac{\sum_{i=1}^{n}(speed_i - speed_{average})^2}{n}}$$

A high standard deviation indicates continuous speed changes, and therefore stop and go phenomena, with a subsequent up and down traffic trend. On the contrary, low standard deviation values indicate a regular traffic trend, with the speed of single vehicles that is near a mean value.

This indicator also regards safety, as stop and go phenomena cause accidents, so a smaller standard deviation of speed indicates smaller stop and go phenomena, that is a more free-flowing traffic and less accidents on average.

The following tables show standard deviation values (in km, as the standard deviation uses the same unit of measurement as the values observed) during the several time intervals, still divided per lane. Nevertheless, the average value of the standard deviation is reported, which can be considered as the dispersion index for the whole carriageway.

Table 4 - Standard deviation of speed on a whole day per lane (km/h).

Lane	***System Off***	***System On***	***Absolute difference***	***% difference***
Fast	18,1	17,5	-0,6	-3,3%
Normal	15,8	15,2	-0,6	-4,0%
Slow	14,9	13,8	-1,1	-7,3%
Average (Carriageway)	16,3	15,5	-0,8	-4,8%

Table 5 - Standard deviation of speed during rush hours per lane (km/h).

Lane	***System Off***	***System On***	***Absolute difference***	***% difference***
Fast	18,7	17,7	-1,0	-5,5%
Normal	16,6	15,8	-0,8	-4,6%
Slow	15,7	14,9	-0,8	-5,1%
Average (Carriageway)	17,0	16,1	-0,9	-5,0%

Table 6 - Standard deviation of speed during peaks per lane (km/h).

Lane	***System Off***	***System On***	***Absolute difference***	***% difference***
Fast	17,6	16,6	-0,9	-5,2%
Normal	15,4	14,6	-0,8	-5,2%
Slow	15,1	14,0	-1,1	-7,5%
Average (Carriageway)	16,0	15,1	-0,9	-6,0%

As shown, a considerable reduction of the standard deviation value can be achieved thanks to the Dynamic Speed Control on, which during peaks reduces by 6% on the whole carriageway.

This result indicates a greater regularity of traffic, and it can also be meant as an increase in safety since it means less accidents.

3.2.5 **Observance of limits**

The limited observance of the speed limits indicated on the VMS indicates that most users probably consider the limits given by the Dynamic Speed Control as a limit to their free-flow speed, or even as a limit imposed to increase safety, and not as a useful recommendation to improve circulation, to increase the journey speed and so reduce the journey time.

4. CONCLUSIONS

The comparison between the days with the Dynamic Speed Control on and the days when the system was deactivated showed that the Dynamic Speed Control installed on the Mestre Beltway improves traffic conditions. In particular during the hours when congestion is higher, an improvement results in the values of the average speed, which increased by 6%, in density, which decreased by 9% and in the time under congestion, which decreased by 21%.The analysis showed a poor observance of the limits given on the VMS on the part of users. An information campaign, which mainly addresses regular users and indicates the real advantages of the Dynamic Speed Control, would make users more aware, with a possible increase in the observance of the limits given and a further improvement in the system effects. Based on data on the standard deviation of speed indicating a reduction of 6% after the introduction of the Dynamic Speed Control, in qualitative terms the system may be said to improve safety by improving flow conditions. This happens because stop and go phenomena generally increase the number of accidents, in particular due to micro collisions. If phenomena of traffic instability are reduced and speed is made uniform, accidents can also decrease. However, this is not supported by data because of the still poor statistical consistency of the history of accidents available. As far as the impact on the environment is concerned, several qualitative considerations may be made. The Dynamic Speed Control, demand being equal, increases the average journey speed and reduces density, above all when congestion is at its highest, thus making traffic free flowing. This improvement, as well as speed made uniform and a reduction in stop and go phenomena (which could not be evaluated empirically because of 5-minute aggregated data) helps improving the driving behaviour. In its turn, this means a reduction of consumption and so of the polluting agents produced. It is however necessary to consider that the increase in the average journey speed causes an increase in the noise produced and, stop and go phenomena and congestion being equal, an increase in the average consumption. Finally, the improvement in the service level on the Mestre Beltway, so an improvement of the offer, could increase the demand, and so the total traffic on the Beltway. The overall impact on the environment (meant as the natural and social sphere in its whole) may also increase. It is therefore necessary to underline that, demand being equal, the Dynamic Speed Control has a positive impact on the environment; nevertheless, if it isn’t supported by systems and policies to control the demand, its advantages may vanish in the medium-long run.

4.1 SUMMARY OF INDICATORS

The summary of the analyses made shows a substantial improvement of traffic conditions. Table 7 shows the values of the indicators analyzed during peaks, which result the most congested intervals.

Table 7 - Summary of on/off indicators.

Indicator	*Time interval*	*System Off*	*System On*	*Absolute difference*	*% difference*
Average speed [km/h]	peaks	68,8	72,7	3,9	5,73%
Average density [vehicles/km]	peaks	57,9	52,5	-5,5	-9,42%
Hours over the threshold [hours:minutes]	peaks	1:45	1:23	-0:22	-21,43%
Speed standard deviation [km/h]	peaks	16,0	15,1	-0,9	-6,0%

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