# Freeway Lab: Testing Dynamic Speed Limits

**Francesc Soriguera Martí**
Assistant Professor, CENIT - UPC-BarcelonaTech, Spain
**Marcel Sala Sanmartí**
Researcher, Barcelona School of Civil Engineering, UPC-BarcelonaTech, Spain

## ABSTRACT

This paper presents the Dynamic Speed Limit (DSL) experiment that took place in June 2013 on the last 13 km stretch of the B-23 freeway accessing the city of Barcelona (Spain). The DSL system installed on that freeway in addition to the high density of surveillance equipment available makes this stretch a suitable highway lab. The objective of the experiment was to construct a comprehensive database of traffic engineering variables on a freeway site when different speed limits apply. Special attention was paid to ensure similar demand conditions. The experiment included the modification of the speed limits on a freeway segment making use of dynamic signals. Detailed measurements of vehicle counts, speeds, occupancies, lane changing maneuvers and travel times were taken. These simultaneous measurements obtained from very different types of monitoring equipment have been grouped into a single database. These include measurements from inductive loop detectors, radar, ultrasound and passive infrared non-intrusive traffic detectors, TV cameras and license plate recognition devices. The potential of this multi-source database is huge. For instance, a preliminary analysis empirically proves that drivers' compliance with dynamic speed limits is very limited, unless speed enforcement devices are present. In addition, it is also proved that lane changing rates increase together with the occupancy level of the freeway. This comprehensive DSL database, unique in its nature, is made publicly available to the whole research community [Link], [1] in order to use up all its information.

The present paper aims to present in detail this DSL experiment and its results and to contribute in the dissemination of the resulting database. This will facilitate its analysis to any interested researcher, and would lead to a better understanding of the causes and effects of DSL strategies on freeways.

Keywords: Dynamic speed limits, freeway traffic, highway lab, database, Barcelona.

## 1. INTRODUCTION AND BACKGROUND

Freeway traffic control by means of dynamic speed limits (DSL) was first introduced in the early 1970s in Germany [2] and one decade after in the Netherlands [3]. Nowadays, DSL is a popular advanced traffic management strategy, with many test implementations in European and American metropolitan freeways

Despite a late dawn, today, the city of Barcelona (Spain) is among the pioneers in large scale implementations of DSL systems, with more than 100 km of controlled freeways. It all started in July 2007, when a 73-measure plan to improve the air quality in the metropolitan region of Barcelona was passed. The plan included the immediate reduction of the speed limits on major freeways accessing the city to 80 km/h (from the preexistent limits of 120 km/h). This was planned as the first step towards implementing a DSL system. The objective was to adapt the speed limits to the prevailing traffic and pollution conditions, maintaining the maximum of 80 km/h limit. The DSL system became operational in a test corridor in January 2009. Later, in January 2011, the maximum speed limit was increased to 100 km/h due to popular demand and keeping the election promise of the new incoming Government in Catalonia. Since then, the system has progressively expanded to more corridors and it is expected to be completed by 2015.

In spite of its expansion and international popularity, the effects of DSL strategies are still not well-known. The usual claimed benefits imply reductions in pollutant emissions [7-9] and accident rates [10-11], as well as congestion relief [12-14]. It is believed that these benefits are the result of the homogenization of traffic flow, which allows for increased capacity and/or for the avoidance of the capacity drop. Works analyzing real traffic data under DSL strategies exist [9, 15-17]. In these, serious work was done with what was available. However, all of them base their results in aggregated traffic data on a test corridor under a specific DSL algorithm. This means that the results obtained are valid in order to test the aggregated corridor performance of a specific DSL algorithm, and therefore are highly algorithm specific. Conclusions on the detailed drivers' behavior when facing different speed limits on the same infrastructure cannot be addressed. The reason for this gap in the literature is the difficulty in measuring suitable traffic data.

In order to understand the fundamental effects of speed limits in a freeway traffic stream, detailed data is needed. Individual vehicle data, without any type of aggregation, makes it possible to compute the homogeneity of speed and occupancy values within the traffic stream and also to count the number of lane changes. In addition, measurements must be obtained within a similar demand context and under clear and different speed limit configurations. This is the most difficult part of the problem. Probably, the only way to measure these data is running a specific experiment in a real freeway with the possibility of radically changing the speed limits from one day to the other, and setting the different scenarios specifically needed for the analysis. There are few freeways around the world capable of dynamically change speed limits and intensively equipped with the surveillance technology required to measure these detailed data. And what is worst, there are even less traffic administrations concerned enough with the scientific community research needs in order to allow such experiments on their heavily demanded freeways.

All the previous has been achieved on the B-23 freeway, accessing the city of Barcelona from the west. This corridor is heavily demanded, with daily recurrent congestion during the morning rush. On the last 13 km accessing the city, a DSL system is installed, with variable speed signs every 0.5 to 1km. The freeway surveillance equipment includes traffic detectors every 0.5 km (on average), TV cameras every 1km and license plate recognition (LPR) devices at both ends of the stretch. And what is more important, the Servei Català del Trànsit (SCT – the Catalan traffic administration) facilitated the experiment. All this makes the B-23 freeway an ideal highway lab.

The objective of the present paper is simply to present in detail such DSL experiment and provide access to the resultant database [Link], [1]. This will allow all the scientific community to make use of a comprehensive and unique freeway traffic database under different speed limit scenarios. The smart analysis of such data should lead to a fundamental advance in the knowledge of DSL effects and their causes.

The rest of the paper is organized as follows. In Section 2 the layout of the freeway stretch where the experiment took place is presented. This includes the geographical location, the physical description and also the traffic demand pattern on a typical weekday morning rush. Next, in Section 3 the DSL system is presented, together with the description of all the technological equipment installed on the experiment site. Section 4 is devoted to the DSL experiment design, including its objectives, requirements and limitations. Section 5 presents a summary of the results. Finally, in Section 6 some conclusions are outlined.

## 2. SITE DESCRIPTION AND TYPICAL TRAFFIC PATTERN

The DSL experiment took place during the first three weeks of June 2013 on the last 13 km stretch of the B-23 freeway in the inbound direction towards Barcelona (see Figure 1). This is one of the main freeways accessing the city, with recurrent daily congestion during the morning rush (from 7:00 to 10:00am). For a typical weekday, peak travel times may exceed more than 3 times the free flow travel time, of approx. 7 minutes (Travel Time Index > 3; see Figure 2d). The total aggregated demand for the 7:00 to 10:00am period is almost 170 000 veh·km for the whole experiment corridor. Figure 2a shows the cumulative traffic demand during a typical weekday morning rush for each section. The importance of the freeway junction at kp 6.89 connecting the B-23 freeway with the Barcelona seaside beltway is evident. Three main bottlenecks exist on this freeway stretch. This can be seen in Figure 2c realizing the three zones with huge average occupancy. The first bottleneck (at kp 7.18) is caused by the merging/diverging conflicts at the major freeway junction. The second one (at kp 3.57) is a diverging bottleneck caused by an off-ramp queue spillback at this location. The third bottleneck is caused by the end of the freeway at a traffic light when entering the city of Barcelona. Figure 3 shows a contour plot of speeds where the congested time – space zones are clearly identified.

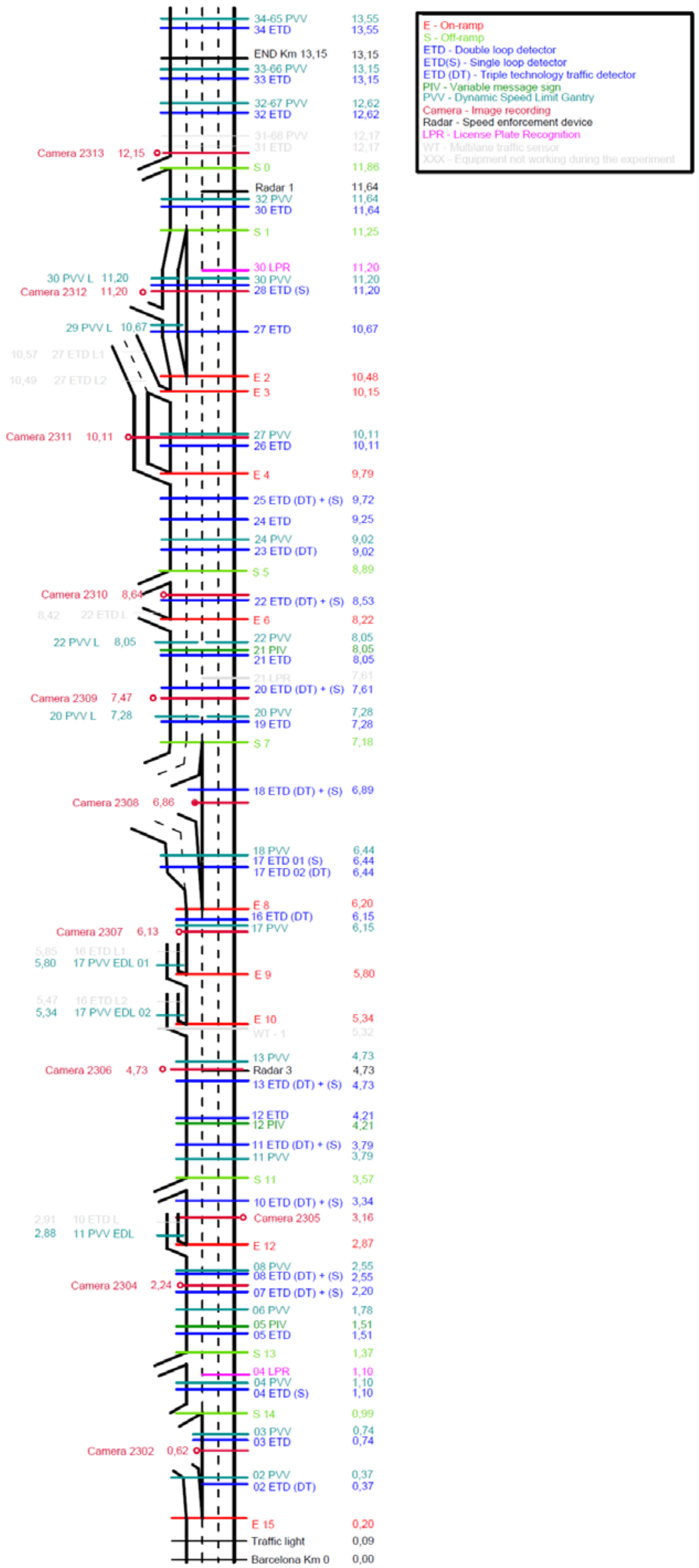
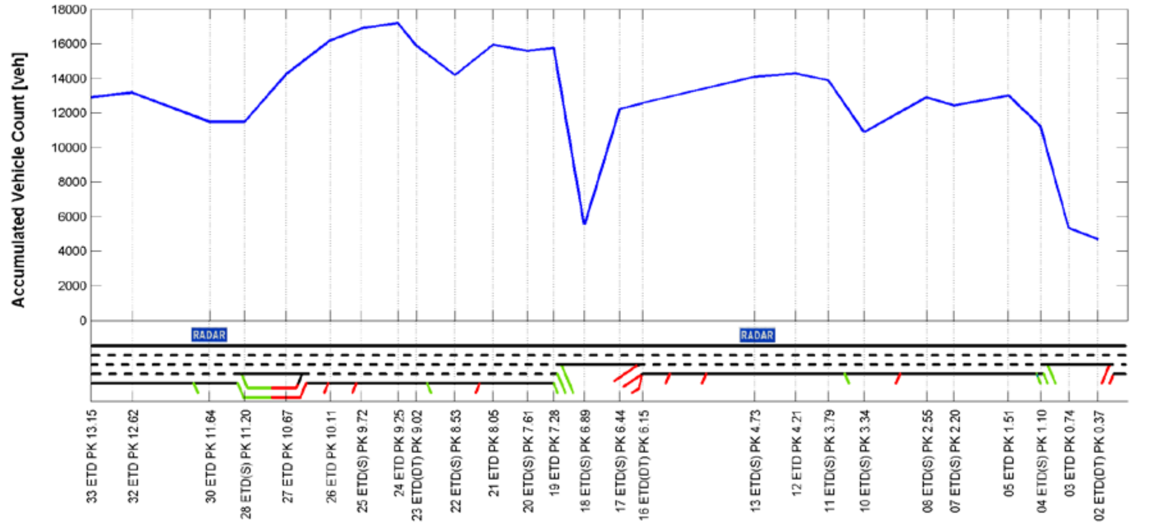
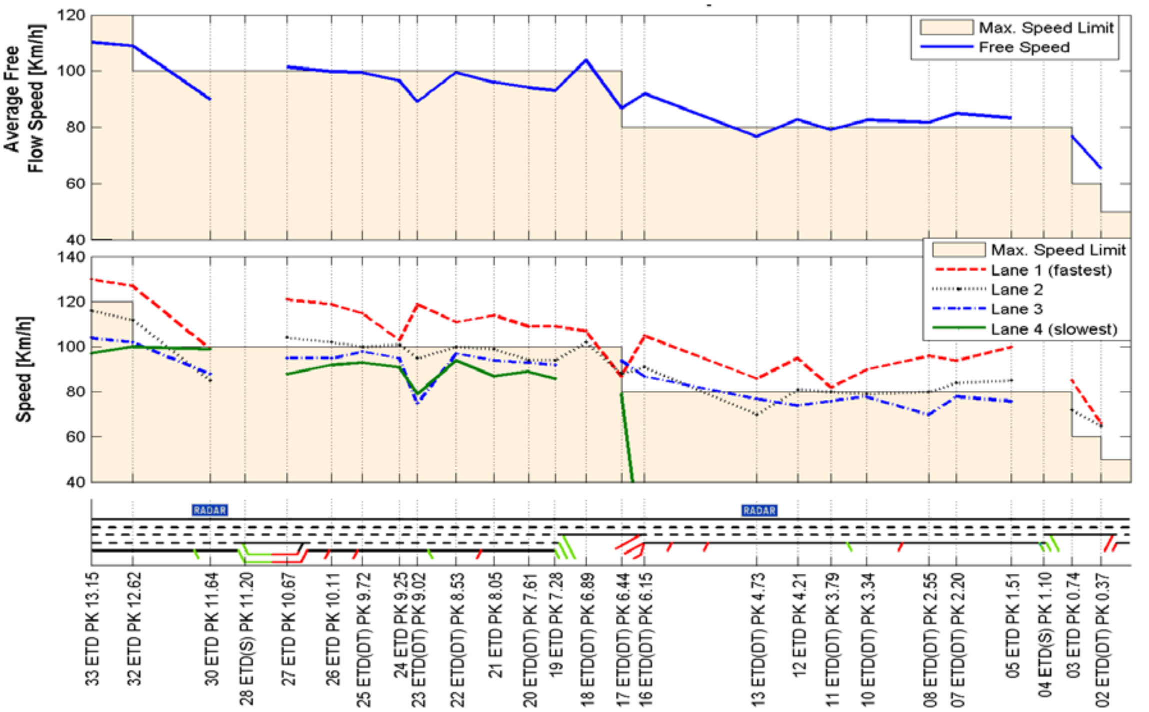


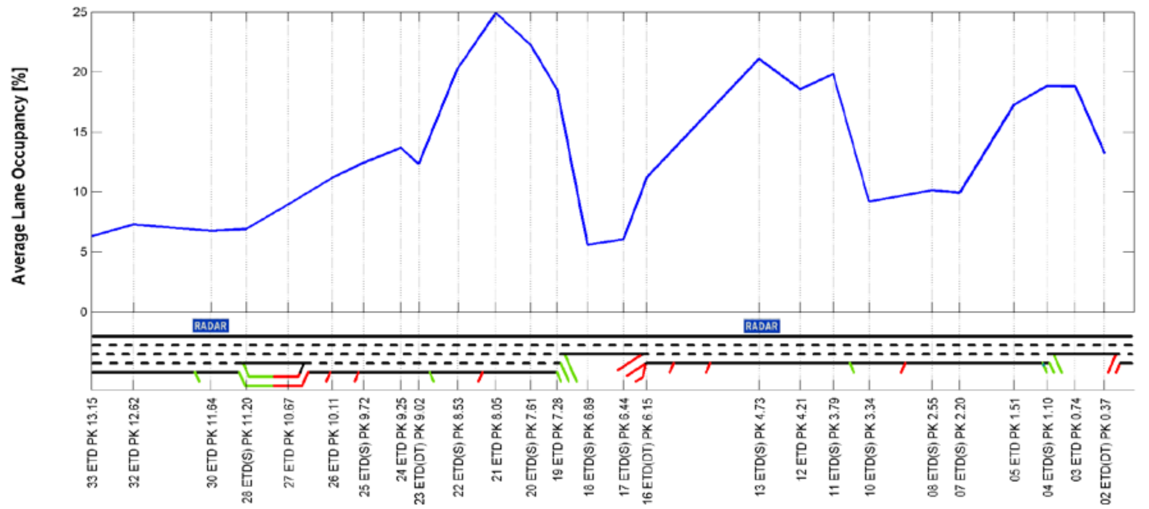
**Fig. 1 – Experiment site layout diagram**


Accumulated Vehicle Count [veh]
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
RADAR
RADAR
33 ETD PK 13.15
32 ETD PK 12.62
30 ETD PK 11.64
28 ETD(S) PK 11.20
27 ETD PK 10.67
26 ETD PK 10.11
25 ETD(S) PK 9.72
24 ETD PK 9.25
23 ETD(DT) PK 9.02
22 ETD(S) PK 8.53
21 ETD PK 8.05
20 ETD(S) PK 7.61
19 ETD PK 7.28
18 ETD(S) PK 6.89
17 ETD(S) PK 6.44
16 ETD(DT) PK 6.15
13 ETD(S) PK 4.73
12 ETD PK 4.21
11 ETD(S) PK 3.79
10 ETD(S) PK 3.34
08 ETD(S) PK 2.55
07 ETD(S) PK 2.20
05 ETD PK 1.51
04 ETD(S) PK 1.10
03 ETD PK 0.74
02 ETD(DT) PK 0.37

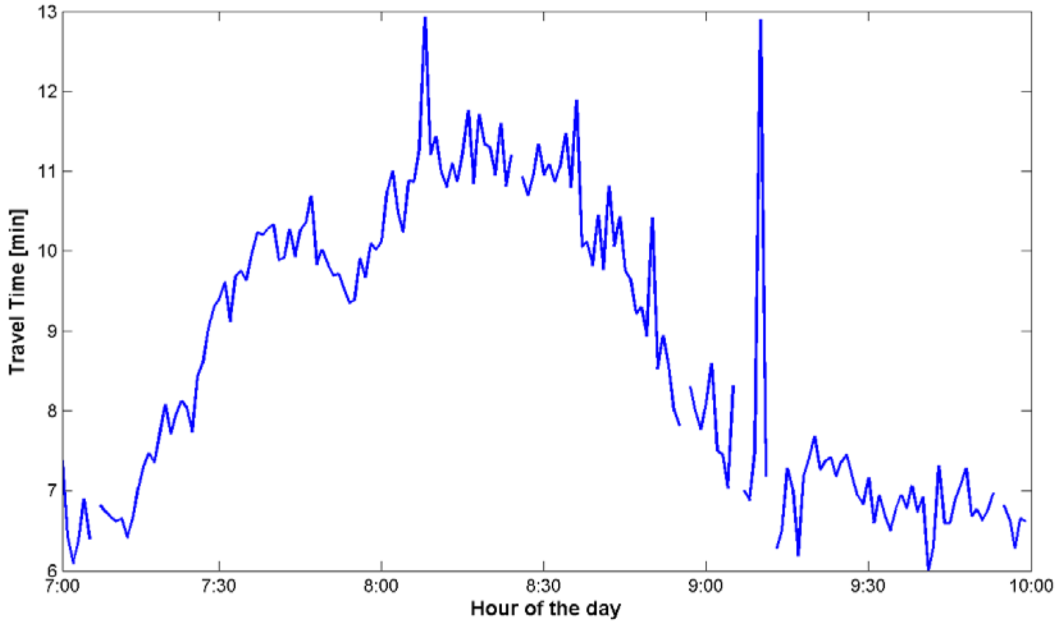
**a)**


Average Free Flow Speed [Km/h]
40
60
80
100
120
Max. Speed Limit
Free Speed
Speed [Km/h]
40
60
80
100
120
140
Max. Speed Limit
Lane 1 (fastest)
Lane 2
Lane 3
Lane 4 (slowest)
RADAR
RADAR
33 ETD PK 13.15
32 ETD PK 12.62
30 ETD PK 11.64
28 ETD(S) PK 11.20
27 ETD PK 10.67
26 ETD PK 10.11
25 ETD(DT) PK 9.72
24 ETD PK 9.25
23 ETD(DT) PK 9.02
22 ETD(DT) PK 8.53
21 ETD PK 8.05
20 ETD(DT) PK 7.61
19 ETD PK 7.28
18 ETD(DT) PK 6.89
17 ETD(DT) PK 6.44
16 ETD(DT) PK 6.15
13 ETD(DT) PK 4.73
12 ETD PK 4.21
11 ETD(DT) PK 3.79
10 ETD(DT) PK 3.34
08 ETD(DT) PK 2.55
07 ETD(DT) PK 2.20
05 ETD PK 1.51
04 ETD(S) PK 1.10
03 ETD PK 0.74
02 ETD(DT) PK 0.37

**b)**


Average Lane Occupancy [%]
0
5
10
15
20
25
RADAR
RADAR
33 ETD PK 13.15
32 ETD PK 12.62
30 ETD PK 11.64
28 ETD(S) PK 11.20
27 ETD PK 10.67
26 ETD PK 10.11
25 ETD(S) PK 9.72
24 ETD PK 9.25
23 ETD(DT) PK 9.02
22 ETD(S) PK 8.53
21 ETD PK 8.05
20 ETD(S) PK 7.61
19 ETD PK 7.28
18 ETD(S) PK 6.89
17 ETD(S) PK 6.44
16 ETD(DT) PK 6.15
13 ETD(S) PK 4.73
12 ETD PK 4.21
11 ETD(S) PK 3.79
10 ETD(S) PK 3.34
08 ETD(S) PK 2.55
07 ETD(S) PK 2.20
05 ETD PK 1.51
04 ETD(S) PK 1.10
03 ETD PK 0.74
02 ETD(DT) PK 0.37

**c)**




d)

**Fig. 2 – Typical weekday traffic demand patterns on the experiment site. a) Cumulative traffic demand for the morning rush. b) Free flow speeds and maximum speed limits. c) Average sectional occupancy. d) Minute average travel times.**

(Note: a) All data are obtained between 7:00 and 10:00am on Tuesday June 4th, 2013, inbound direction. b) Free flow speeds are computed using per lane minute average speeds. The median of the 30 highest average speeds between 7:15 and 10:00 is selected. Sectional free flow speed is computed as a weighted average of per lane free flow speed. The weights are the relative flows on each lane. c) 04 ETD(S) and 28 ETD(S) are simple loop detectors without speed measurements)

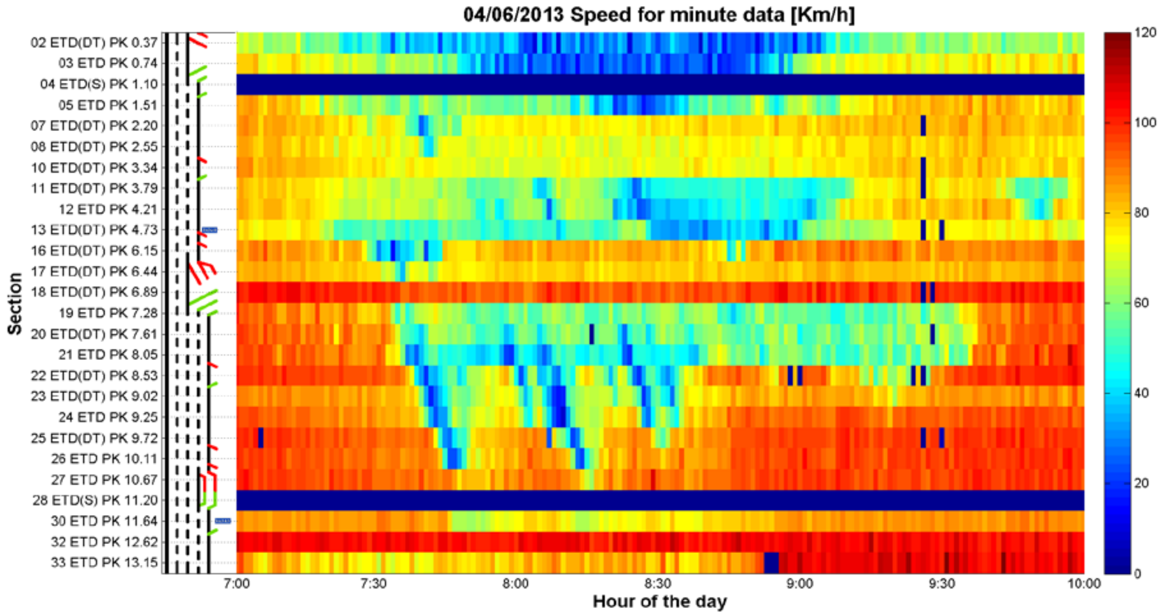



**Fig. 3 – Speed contour plot.** Between 7 and 10am on Tuesday. June 4$^{th}$, 2013.

## 3. DSL SYSTEM AND SURVEILLANCE EQUIPMENT INSTALLED

Surveillance equipment properly working during the experiment period is shown in the layout diagram in Figure 1. All the equipment can be remotely controlled from the traffic management center (TMC). The adopted surveillance strategy included the installation of traffic detectors every 0.5 km, capable of measuring flows, occupancies and speeds. Several detector technologies are installed: traditional inductive double or single loop detectors (called ETD and ETD(S) detectors in the present paper) and non-intrusive detectors (called DT detectors) that obtain their measurements from 3 redundant technologies: Doppler radar, ultrasound and passive infrared detection. By default, all types of detectors compute, per lane and every minute, the total vehicle count [vehicles], the time-mean speed [km/h] (i.e. arithmetic average of individual speeds measured during the minute) and the detector occupancy [%].

All the detectors are installed on the main trunk lanes. Only off-ramp “S7” and on-ramp “E8” are monitored. In general, there is only one ramp in between consecutive detectors so that the ramp flow could be approximately computed assuming vehicle conservation and neglecting detector drift. The settings of any type of detector can be modified in order to measure individual vehicle actuations (in addition to the default minute averages).

The detector system is complemented with TV cameras approximately every km. TMC operators use the cameras to obtain direct visual information in order to support their decisions when some incident takes place. The use of the cameras is completely visual, without any type of automatic processing of the images.

Finally, the surveillance system also includes two license plate recognition devices (LPR), at both ends of the experiment site. LPR are only installed in the middle and fast lanes. These are used to measure the travel time on the stretch. The system tries to pair the licenses read at both locations in order to compute the travel times. Results are reported as minute averages. There are some minutes without any pairing, and travel time is void. Incorrect matching or vehicles that detour or stop in between LPR devices implies the existence of outliers in these data (see Figure 2d).

All these surveillance equipment support the DSL system. When the DSL system is active, “adequate” speed limits are computed every 5 minutes, and are posted on the dynamic signs installed on overhead gantries (called PVV in the present paper). There is a maximum speed sign for every lane, so that different speed limits could be posted for different lanes. However, by default, the DSL algorithm computes sectional (i.e. for all lanes) speed limits. The heuristics behind the DSL algorithm are simple. First, the corridor is divided into sections. Each section is defined by the dynamic speed limit sign at its upstream end, with an approximate length of 1 km. The posted speed limit for the section is then computed as the minimum amongst two values:

- The average speed measured by the detectors within the section, rounded down to the closest 10 km/h multiple.
- The speed limit posted in the next downstream signal increased at a rate of 10 km/h for every km of separation.

Finally, the posted speed limit cannot be lower than 40 km/h or higher than the maximum speed limit for that section. Speed limits are enforced at two spots of the corridor using radar units (see Figure 1).

## 4. THE EXPERIMENT

The experiment was designed to provide the most suitable data in order to answer the research questions that remain unsolved. Table 1 summarizes the research questions to be addressed and the related requirements on the experiment design.

There are also some limitations that affect the results of the experiment. The first and more obvious is that, being an empirical traffic experiment, the same demand in all DSL contexts cannot be assured. The experiment design pays attention to ensure similar demands, but in real experiments this is always an issue. This problem is made worst by the fact that merging and diverging bottlenecks are predominant and its capacity depends on the merging/diverging demands. Other limitations are imposed by the technical capabilities of the TMC regarding the "special" settings of equipment. For instance, only 3 TV cameras can record simultaneously and only 4 detectors can simultaneously measure individual actuations. This imposes tight restrictions to the experiment design. Finally SCT, the traffic administration, imposed some additional limitations to the experiment in order not penalize the drivers in excess. This includes a minimum of 50 km/h speed limit in free flowing sections, and a maximum length of 5 km where this minimum speed limit could be posted simultaneously.

### 4.1 Experiment Design

The experiment took place between 7 and 10am capturing the whole morning rush. Only Tuesdays, Wednesdays and Thursdays were candidate days for the experiment. This ensures, to some extent, a similar traffic demand on the corridor. The experiment did not take place in case of any type of previous incident upstream or downstream of the experiment site. Rain or bad weather also implied to abort the experiment.

| Issue | | Description | Experiment requirements |
|---|---|---|---|
| Drivers compliance | | • Do the drivers comply with DSL? (in particular when speed limits are low and traffic density is moderate).<br>• What is the effect of enforcement devices on drivers' compliance? | • Is desirable to look for high compliance rates. Otherwise, the only conclusion would be the lack of compliance. Therefore speed limit enforced sections are preferable for detailed analysis. |
| Macro Effects | Bottleneck capacity | • Can speed limits have a positive effect on bottleneck capacity? When?<br>• Can speed limits attenuate the capacity drop phenomenon in the transition to congested flow? (i.e. stabilize the maximum flow).<br>• Can speed limits attenuate the surge and drop behavior of bottleneck discharge flows? | • Measurements need to be taken upstream of some bottleneck (i.e. queued traffic) and downstream of it (i.e. free flowing at capacity).<br>• It would be desirable to capture the congestion onset and dissolve periods (i.e. the whole peak period). |
| | Mainline metering | • Can low speed limits create an "artificial" bottleneck?(so that the mainline flow could be metered by using speed limits) | • Create contexts where the speed limit becomes an active bottleneck (i.e. impose very strict speed limits on sections flowing near capacity). |
| | Fundamental diagram and queue propagation | • How does the flow-density relationship evolve under different speed limits?<br>• How this affects the queue evolution? (shock wave speeds) | • Speed limits on the experiment site should follow a predetermined plan where most of the occupancy vs speed limit scenarios are replicated. |
| Micro Causes | Vehicular speed distribution | • Is the vehicular speed distribution modified by different speed limits? (intra lane and across lanes)<br>• Is the speed variance reduced? (speed homogenization) | • Individual vehicle data is needed. |
| | Stop & go attenuation | • Can speed limits attenuate the stop & go phenomenon?<br>• In case it exists, does this attenuation increase the queue discharge rates? | |
| | Inter lane occupancy | • Can speed limits homogenize the occupancies of the various lanes? | • Avoid sections near on/off ramps, where lane occupancy is affected by the merging/diverging. |
| | Lane changing rates | • Can speed limits reduce the discretional lane changing rates? | • Avoid sections where mandatory lane changes are predominant, near on/off ramps.<br>• The quality of the video recordings should be enough to count the number of lane changes. |

**Table 1 – Research questions to be addressed**

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| | | Day#1 | Day#2 | Day#3 | Day#4 | Day#5 | Day#6 | Day#7 |
|---|---|---|---|---|---|---|---|---|
| Dynamic Speed Limit Gantries | 33-66 PVV (13.15) | Transitional speed limits | | | | | | |
| | 32-67 PVV (12.62) | | | | | | | |
| | 32 PVV (11.64) | SCT | 100 | 80 | 50 | 100 | 80 | 80 |
| | 30 PVV (11.20) | SCT | 100 | 80 | 50 | 100 | 80 | 80 |
| | 30 PVV L (11.20) | SCT | 80 | 80 | 50 | 80 | 80 | 80 |
| | 29 PVV L (10.67) | SCT | 100 | 80 | 50 | 100 | 80 | 80 |
| | 27 PVV (10.11) | SCT | 100 | 80 | 50 | 100 | 80 | 80 |
| | 24 PVV (9.02) | SCT | 100 | 80 | 50 | 100 | 80 | 80 |
| | 22 PVV (8.05) | SCT | 100 | 80 | 50 | 100 | 80 | 80 |
| | 22 PVV L (8.05) | SCT | 100 | 80 | 50 | 100 | 80 | 80 |
| | 20 PVV (7.28) | SCT | 80 | 80 | 50 | 80 | 80 | 80 |
| | 20 PVV L (7.28) | SCT | 80 | 80 | 50 | 80 | 80 | 80 |
| | 18 PVV (6.44) | SCT | 80 | 80 | 80 | 80 | 80 | 80 |
| | 17 PVV (6.14) | SCT | 80 | 80 | 80 | 80 | 80 | 60 |
| | 17 PVV L01 (5.80) | SCT | 80 | 80 | 80 | 80 | 80 | 60 |
| | 17 PVV L02 (5.34) | SCT | 80 | 80 | 80 | 80 | 80 | 60 |
| | 13 PVV (4.73) | SCT | 80 | 80 | 80 | 80 | 60 | 40 |
| | 11 PVV (3.79) | SCT | 80 | 80 | 80 | 80 | 60 | 40 |
| | 08 PVV (2.55) | SCT | 80 | 80 | 80 | 80 | 60 | 40 |
| | 06 PVV (1.78) | SCT | 80 | 80 | 80 | 80 | 60 | 40 |
| | 04 PVV (1.10) | SCT | 80 | 80 | 80 | 80 | 60 | 40 |
| | 03 PVV (0.74) | SCT | 60 | 60 | 60 | 60 | 60 | 40 |
| | 02 PVV (0.37) | SCT | 50 | 50 | 50 | 50 | 50 | 40 |
| TV Cameras (High quality: 30 fps and 536x400 pixels) | | 2306 | 2312 | 2312 | 2312 | 2306 | 2306 | 2306 |
| | | 2305 | 2310 | 2310 | 2310 | 2305 | 2305 | 2305 |
| | | 2304 | 2309 | 2309 | 2309 | 2304 | 2304 | 2304 |
| Raw Detectors (Individual actuations) (ETD – Double loop detector) (DT – Non Intrusive detector) | | 13(DT) | 30 (ETD) | 30 (ETD) | 30 (ETD) | 13 (DT) | 13 (DT) | 13 (DT) |
| | | 12 (ETD) | 27 (ETD) | 27 (ETD) | 27 (ETD) | 12 (ETD) | 12 (ETD) | 12 (ETD) |
| | | 11 (DT) | 21 (ETD) | 21 (ETD) | 21 (ETD) | 11 (DT) | 11 (DT) | 11 (DT) |
| | | 8 (DT) | 19 (ETD) | 19 (ETD) | 19 (ETD) | 8 (DT) | 8 (DT) | 8 (DT) |

**Table 2 – DSL and surveillance equipment configuration.**

All traffic detectors were set to store minute aggregations of vehicle counts, occupancy and average speed. In addition, 4 of them were configured to also measure individual actuations (see Table 2). 3 TV cameras were selected (see Table 2 and Figure 4) to record simultaneously high quality videos of their influence zones (i.e. 30 fps and 536 x 400 pixels) with the objective of counting lane changing activity. These selections were made taking into account that the resulting detailed measurements should capture different traffic conditions (i.e. congested and free-flowing), some of them should be near the enforcement devices so that the compliance with the speed limits is higher, and others should be farther apart in order to provide data to assess the effects of the enforcement. Finally, whenever possible they should be far apart from junctions, to avoid mandatory lane changes. In addition, LPR measured average travel times in a per minute basis.

Table 2 summarizes the DSL contexts and the surveillance equipment subject to special settings. Speed limit enforcement radars were active, but tickets were waived during the experiment periods. No specific information about the experiment was given to the drivers.

The experiment design on Table 2 meets all the aforementioned restrictions. The limitations in the number of simultaneous equipment to measure detailed data and in the length of freeway with minimum speed limits suggested to divide the test site in two parts: the outer part (comprising 32 PVV to 22 PVV) and the inner part (13 PVV to 4 PVV). In between there is a transition zone. For each part the following scenarios are defined:

- Maximum speed limit. 100 km/h for the outer part (Day#2) and 80 km/h for the inner part (Day#5).
- Minimum speed limit. 50 km/h for the outer part, mostly free flowing (Day#4) and 40 km/h for the inner part, mostly congested (Day#7).
- Medium speed limit. An intermediate scenario between a) and b). This is 80 km/h for the outer part (Day#3) and 60 km/h for the inner part (Day#6).
- Dynamic speed limits. According to the Servei Català del Trànsit (SCT) algorithm for the whole test site (Day#1).

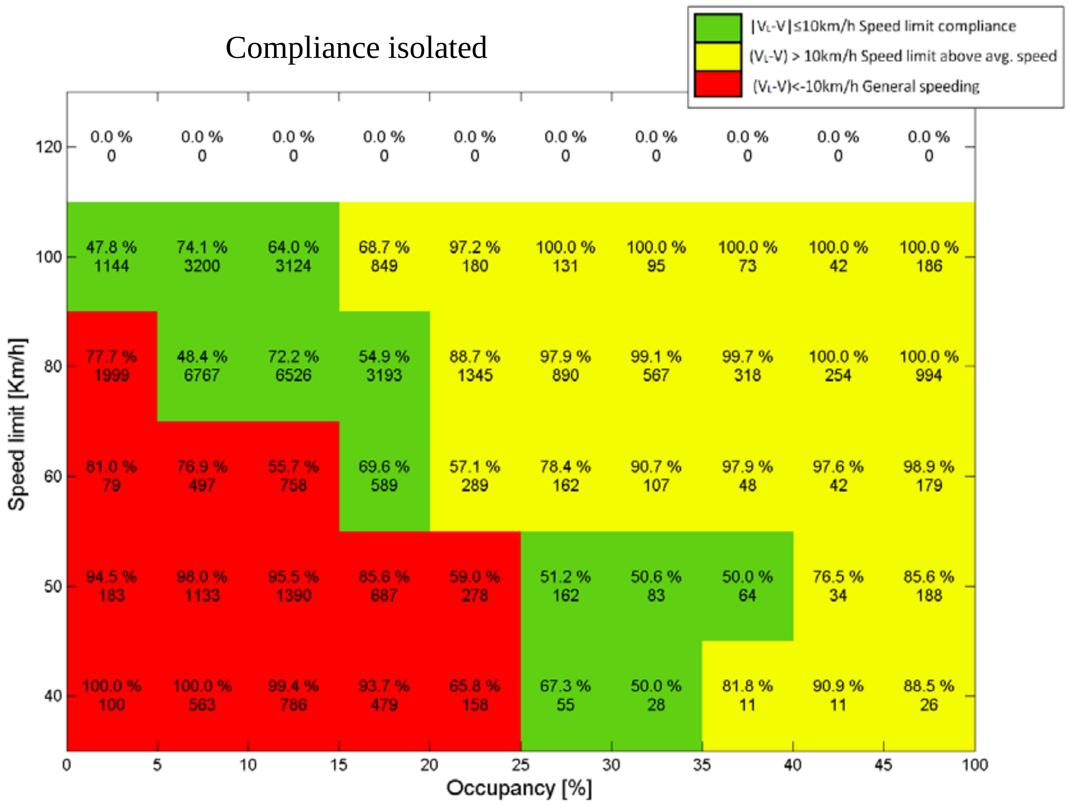

**Fig. 4 – TV camera perspectives**

## 5. EXPERIMENT RESULTS

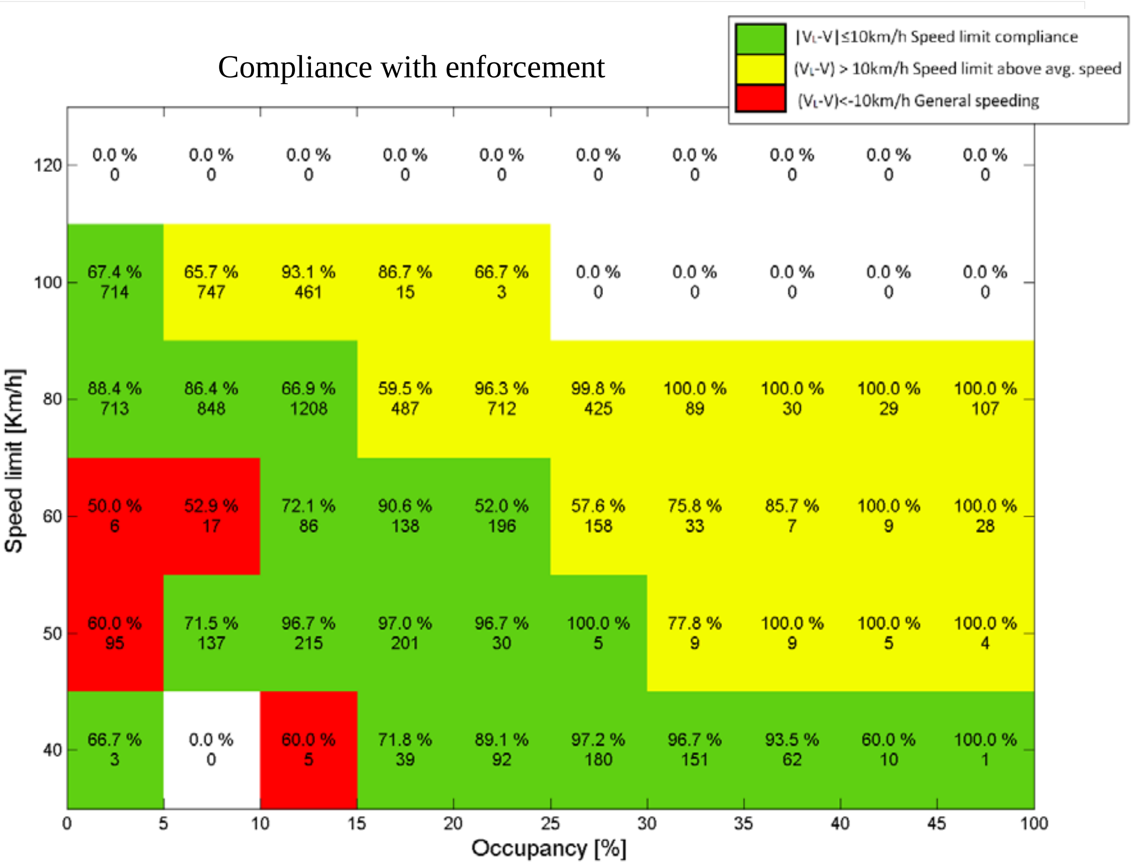
The experiment took place during the period comprised between May 30th and June 19th, 2013. The overall traffic demand on the corridor during the seven experiment days did not deviate more than 0.9% from the average.

### 5.1 Drivers' Compliance with DSL

Figure 2b shows that maximum speed limits are approximately fulfilled in average. However, if only considering the fastest lane, the speeding is notorious. Furthermore, results obtained from the experiment show that generalized speeding happens when lower than maximum speed limits are in force. In such situations, speed limits are only strictly fulfilled in the sections with radar enforcement. This is evident from Figure 5, where a contour plot shows the difference between the speed limit and the average speed for a given occupancy range on all the detectors in the test site. Red regions indicate speeding is the majority for that specific speed limit – occupancy cell, green indicates compliance and yellow indicates speed limit far above the average speed (i.e. ineffective speed limit). On each cell of the contour plot the percentage of the majority and the total number of observations (i.e. minutes) in the cell are shown. Results are shown for isolated detectors (far from any speed signal and enforcement device; see Figure 5a) and for detectors with speed enforcement (see Figure 5b).




**a)**




**b)**

**Fig. 5 – Speed limit compliance. a)Isolated detector. b) Detector with speed enforcement device**

The contour plot for isolated detectors (Figure 5a) shows a green region on the diagonal of the speed – occupancy contour plot, yellow above it and red below it. This means that average speed follows the typical speed – occupancy relationship, without caring about the speed limit in force. If speed limit happens to coincide with the average speed dictated by the prevailing occupancy level, then it is fulfilled. Otherwise, it is not. If speed limit is lower, speeding is generalized. If it is higher, it is ineffective. In conclusion, dynamic speed limits do not have a generalized effect on drivers' behavior.

On the contrary, if only sections with speed enforcement are considered (see Figure 5b), speeding is almost eliminated. In such situations, dynamic speed limits affect drivers' behavior. However, the DSL system is not capable of enabling higher average speeds for high occupancy values that would lead to capacity increase. That is why the yellow region remains.

### 5.2 Lane Changing Activity

A rough analysis of the lane changing activity indicates that the great majority of discretionary lane changes take place during congested periods. A conclusive prove of this fact is obtained by plotting time series of the cumulative lane changing activity together with cumulative vehicle count and occupancy. Figure 6 shows that congestion reached

Camera 2309 location around 8:30am. This can be seen by realizing the opposite trends in cumulative occupancy (slope increase in the T-curve) versus cumulative count (slope decrease in the N-curve) [18]. It is also clear from Figure 6 that the lane changing rate (slope of L-curve) increased notably once the congestion appeared. Although further research is needed, this result exemplifies the potential of the database in empirically proving ideas that until now were only assumptions.

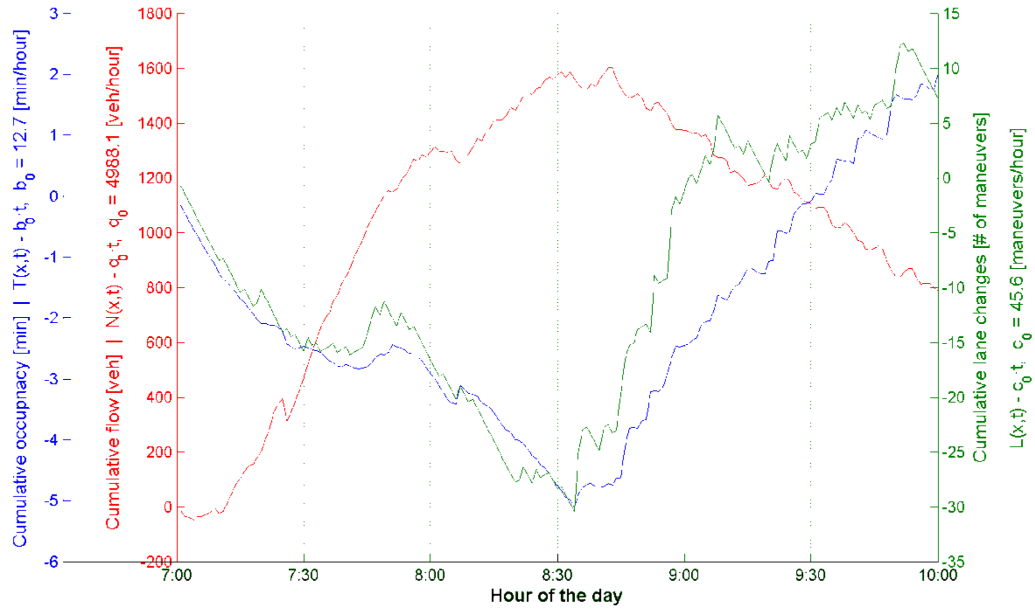



**Fig. 6 – Oblique cumulative count (N), occupancy (T) and lane change (L) curves.**
Note: 1) Data is obtained from Camera 2309 and detector 20ETD(S) on Wed. 5th May 2013 (Day#4). 2) Oblique cumulative curves imply the subtraction of background values in order to facilitate the interpretation of the plot [19]

## 6. CONCLUSIONS

This paper presents a comprehensive database of traffic variables on a unique freeway site when different speed limits apply and under similar traffic demand contexts. This includes simultaneous measurements from very different surveillance technologies. The resulting database is made available to the whole research community [Link], [1] in order to provide a solid empirical ground from where to build and validate theories and models.

The availability of such an empirical database should lead to more conclusive proves in relation to the effects of DSL strategies. Possible research topics may include (but are not limited to) the DSL ability to increase bottleneck capacities and reduce the capacity drop phenomenon, or to avoid temporary restrictions within queues due to stop & go traffic and therefore increase queue discharge rates. The ability of DSL strategies to restrict the mainline flow on a freeway (i.e. mainline metering) by creating artificial bottlenecks in otherwise free flowing sections could also be investigated. Or the drivers' compliance to dynamic speed limits, specifically when they are more counterintuitive (e.g. very low speed limits in uncongested traffic). Preliminary results show that DSL are only strictly fulfilled on section with active enforcement. Also the causes of these effects should be subject of research, like the speed harmonization under DSL, the reduction in the lane utilization variability, the reduction of discretionary lane change maneuvers, the DLS effects on traffic instabilities (i.e. stop&go) and the modification of vehicle headway or spacing distributions. Initial investigation shows that the lane changing activity is mainly related to the occupancy level of the freeway lanes.

## ACKNOWLEDGEMENTS

The author acknowledges the collaboration of Jordi Janot and Dr. Mónica Menéndez from ETH Zurich for their work on the preliminary data analysis. Advice provided by Josep Maria Torné (BarcelonaTech) in the construction of the database and by Anthony Patire and Robert Campbell (PATH-UC Berkeley) and Bernat Goñi (TU Delft) in the video image processing is also acknowledged. This experiment would not have been possible without the collaboration and implication of the whole staff of the Servei Català del Trànsit. From his director Joan Josep Isern and his executive staff. to those who helped in the experiment design and execution Inma Selva. Jan Peña and specially Òscar Llatge who pushed for the experiment to become a reality. Finally. the hard work at the TMC during the experiment days of Javi Romero and Carles Argüelles (ute acc. sur acisa-aluvisa) and their staff is gratefully acknowledged. The experiment has been partially funded by the Servei Català del Trànsit (CM-12/2013) and by the Spanish Ministry of Science and Innovation (TRA2009-14270/MITRA).

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