 DOI: 10.20858/tp.2016.11.1.7

variable speed limit; speed acceptance; driver behavior; highway management

Michał MATOWICKI*, Ondřej PŘIBYL
Czech Technical University, Faculty of Transportation, Department of Applied Mathematics
Na Florenci 25, Prague 110 00, Czech Republic
Corresponding author. E-mail: Matowicki.m@gmail.com

SPEED COMPLIANCE IN FREEWAY VARIABLE SPEED LIMIT SYSTEM – CASE STUDY OF THE PRAGUE CITY RING

Summary. Many previous studies have confirmed the strong relationship between speed compliance and the frequency and severity of traffic accidents. Variable speed limit (VSL) system as a measure to improve traffic safety enables the freeway system to change its posted speed limit based on various traffic and environmental conditions. Such system helps drivers to recognize the upcoming events, to adjust their driving style and in such way to address speed variation of the traffic flow. This is called speed harmonization. Although many studies researching the effect of VSL system on the traffic stream can be found, there are only few addressing its influence on the drivers behavior, particularly focusing on their tolerance limit and compliance, which has crucial meaning for future design of controlling algorithms. This study was prepared to inspect this grey area by studying the data from the VSL system at Prague city ring, describing the influence of the highway management system and its influence on drivers.

ANALIZA PRZYPADKU PRZESTRZEGANIA PRĘDKOŚCI USTANAWIANYCH PRZEZ SYSTEM ZMIENNYCH OGRANICZEŃ PRĘDKOŚCI NA OBWODNICY PRAGI

Streszczenie. Wiele opisanych przypadków potwierdza silny związek między przestrzeganiem ograniczenia prędkości oraz częstotliwością i ciężkością wypadków samochodowych. System zmiennych ograniczeń prędkości VSL jest narzędziem służącym do poprawienia bezpieczeństwa ruchu drogowego (BRD). Pozwala on na zmianę obowiązującego ograniczenia prędkości w odpowiedzi na zmianę warunków ruchu drogowego, zmniejszając różnice prędkości poszczególnych kierowców, oraz informuje kierowców o wydarzeniach na drodze. Efekt ten jest nazywany harmonizacją prędkości. Chociaż wielu badaczy skupiało się na wpływie systemu zmiennych ograniczeń prędkości na zwiększenie bezpieczeństwa ruchu dtogowego, niewielu zajmowało się zakresem tolerancji oraz dostosowywaniem się kierowców do wskazań systemu. Aspekty te są jednak kluczowe dla projektowania przyszłych algorytmów sterujących tym systemem. W artykule podjęto próbę zbadania i przeanalizowania tych zależności, na podstawie informacji z obwodnicy Pragi.

1. INTRODUCTION

Nowadays, Highway Management Systems are of the highest need. Such systems react in the real time to different traffic situations in order to improve the traffic flow characteristics. To achieve this goal, different management strategies, such as speed harmonization through Variable Message Signs

(VMS), ramp metering, informing drivers, lane management and others are used. Within this paper, we focus on speed harmonization strategy, since it is an essential part of most highway management systems. Based on information from various traffic as well as for example weather sensors, such systems impose different speed limits. This measure leads not only to improvement of safety since vehicles drive with similar speeds (thus speed harmonization), but even to improvement of throughput and capacity of the road segment. The latter was proved successful also for the highway management system on the Prague city ring [1].

The above mentioned positive effects are however true only when the drivers adjust their speed to the indications of the system. It is known, that not all drivers are fully compliant with the speed limits. However the magnitude of the drivers compliance has not been ever demonstrated. Such compliance certainly dependents on several aspects, such as level of enforcement, level of drivers acceptance and trust in the highway management system, the geographical region or cultural habits.

In order to gain more insight into the topic of drivers compliance, the authors analyze data from one particular highway management system with the objective to be able to describe the effect of different speed limits on the parameters of the traffic flow. This paper does not provide a general answer valid for all highway management systems. It however describes tools and processes which can be used generally.

The study was initiated by a particular research project, SIRID[1], where different control algorithms were evaluated on a microsimulation model. In order to be able to do such evaluation, the reaction of the drivers for different speed limits must be provided as an input to the model. And that was one of the major motivations for this study.

2. PROJECT DESCRIPTION

The paper is analyzing data from the highway management system put into operation in the year 2010 on the Prague city ring. The system collects traffic data from inductive loops and video sensors. Additional information about weather is collected from meteorological stations.

The system covers over 20 km and connects major interstate highways D5 and D1. Gantries spaced about 1.2 km from each other are installed in both directions. These gates we can see on the fig. 1 below, where map of city of Prague is presented along with whole city ring. First constructed sections are marked with red color, section opened in year 2010 with installed VSL system is marked by dark blue color and light blue is corresponding for planned sections of Prague city ring that have not been constructed yet.

The traffic data, among others for example traffic flow (veh./time), occupancy (%), speed (km/h) or vehicle class (8 classes), are collected from each road segment and aggregated directly at the gantries into one-minute intervals. To determine the speed limit on the freeway, the Prague VSL system currently uses an algorithm based on decision trees. Data aggregated further into three-minute intervals from all road sections are preprocessed and used to limit the speed to 120 km/h, 100 km/h, 80 km/h or 60 km/h. The decision is based on three traffic flow parameters: intensity (veh./h), speed (km/h) and density (veh./km). In order to avoid oscillation of the speed limits, a hysteresis is ensured by smoothing of the measured data, the already mentioned aggregation as well as through using different boundaries for turning on and off the speed limits.

Data from three selected gantries depicted in Fig. 1 for March, 2014 were analyzed within this paper. Daily traffic volume varies from 12,000 to 15,000 vehicles in each direction, accommodated at 4 lane highway, 2 lanes in both directions.

The first idea of using just any gantry for the data analysis was proven to be wrong. The gantries displaying the speed limit are placed direct above the traffic sensors measuring the data used in this analysis. It is a common nature that drivers seeing the speed limit start to slow down but they do not drive at the target speed already under the speed limit sign. Typically that is the place where they start with this slowing-down manoeuvre. For this reason, the traffic sensor located below this first gantry is

[1] SIRID – a project sponsored by the Technological Agency of Czech Republic.

not so relevant and should be not used in the analysis. Additionally, in case they see on the next gantry that the speed limit was canceled and there is no speed limitation any more, they speed up rather quickly, so the next traffic sensor is also not relevant since the drivers are cruising under unlimited speed limit already. This implies that a speed limit imposed on one gantry only, cannot be sufficiently measured by the sensors at the entry and exit point of the section.

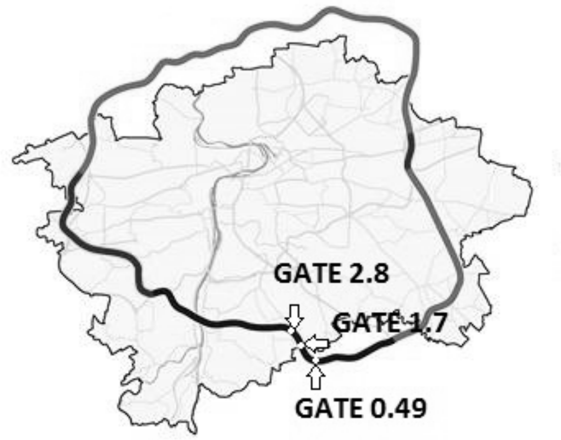


Fig. 1. The Prague city ring with depicted analyzed gates
Rys. 1. Obwodnica Pragi z wskazanymi analizowanymi bramami

For these reasons, the analysis within the paper requires that there is the same speed limit imposed on all four gantries considered within the study. In such case, only the sensors under the second to fourth gantry are considered and used for the analysis. This approach assures steady state needed for proper results.

The purpose of this analysis is to find correlation among the speed limits displayed on the VMS (130 (No Limit), 120 km/h, 100 km/h, and 80 km/h) and the measured average speeds as well as the speed standard deviations.

3. LITERATURE REVIEW

The need for understanding this problem has been already identified by several researchers, especially in Europe. They mostly focus on traffic safety. Allaby, Hellinga and Bullock [2] studied VSL from the perspective of safety and operational impact of a control strategy for freeway applications. The objectives of this study were to design an evaluation framework for a candidate Variable Speed Limit Signs (VSLS) control algorithm under real traffic conditions, to perform an extensive analysis of the proposed algorithm. The results of the analysis for the original VSLS control algorithm suggested that the implementation of the system could provide improvements in safety but that these would be obtained at a cost in terms of increased travel times. These impacts were not consistent for all traffic conditions. Safety improvements were achieved for heavily congested (peak period) and moderately congested (near-peak period) traffic conditions, but a new reduction in safety resulted for uncongested conditions (off-peak period).

Another simulation based research study revealed that VSL impacts and safety benefits are very sensitive to drivers compliance and that the level of safety was positively correlated with compliance level ([3]). This work supports previous results from [4] for a simulation study of a Florida freeway where safety benefits were also determined.

Several studies ([1], [5]) found impact of different VSL control strategies on traffic flow as to ensure speed harmonization and to prevent the flow breakdown.

On the other hand reference [6] investigated with use of microsimulation the relation between effectiveness of the VSL system and the compliance level of the drivers. Significant differences in effectiveness level depicts need of investigating the compliance and tolerance level of VSL level by drivers as necessary mean to perform authoritative simulations and well design of the future VSL systems steering algorithms.

Another important issue related to VSL systems was pointed out by [7] where drivers limit of tolerance for information was examined. According to Finnish research drivers were less likely to recall the warning sign when it was in the vicinity of the fibre-optic speed limit sign than in the vicinity of the fixed speed limit sign. The investigation here was held with respect to drivers ability to absorb the information about weather conditions but even so, it doubted effectiveness of VMS in comparison to fixed signs.

However, any of the presented researches did not provide an answer to the question how does the imposed speed limit affect the driving behaviour of vehicles, which is expected to vary in different cultural conditions.

4. DATA ANALYSIS

Data collected from the Prague city ring was post processed and categorized into several groups with different driving conditions, where total participations did not exceed 2 mm per square meter. Such action was taken to separate and differentiate drivers behavior in different driving conditions. It was very important for us to determine whether drivers react truly on changes in VSL system or maybe the change in their behavior is a result of the increased traffic density.

All the data used for further analysis were therefore divided into categories presented further in this capitol. The described data contain information about the behavior of drivers during all the period of VSL system activation, as well as their behavior 20 minutes before and after VSL activation. Data about vehicles counts and speeds that were not influenced by any limits, were used as control group. As expected, their behavior of the drivers is strongly influenced by dense traffic on the highway and therefore is less useful in examination of behavior of individual drivers. The categories of analyzed data were established as follows:

A. Daylight driving at low traffic

This category contains all the traffic data after 5 a.m. and before 10 p.m. where combined traffic volume for both lanes leading in one direction did not exceed 15 veh./min.

B. Night driving at low traffic

This category contains all the traffic data after 10 p.m. and before 5 a.m. where combined traffic volume for both lanes leading in one direction did not exceed 15 veh./min

The case in which there is a high volume of vehicles is not considered within this analysis. In such case, the vehicles are not free to react to the VSL, since their speed is affected by the neighboring vehicles.

For each of these predefined categories, traffic data were extracted and grouped into different sub-categories according to speed limits activated. These groups were preprocessed to eliminate empty data cells and calculate parameters such as average vehicle speed and standard deviation within the samples, describing data.

Fig. 2 illustrates a typical situation - behavior of the drivers within the first minutes after a speed limit of 100 km/h is imposed. This situation describes morning hours after traffic peak with volume of approximately 10 veh./min (i.e. Category A). This figure suggests that there is no significant visible change in the traffic flow characteristics caused by the VSL. This was the first impulse to analyze the data in more details.

First of all, the speed values were put into histograms to gain more insight into its characteristics (Fig. 3 and Fig. 4). In these histograms the visible spread of speeds could be seen in each examined case. Additionally groups of “speeding vehicles” and “always slow” vehicles were visible on both ends of histograms. Such vehicles do not change their speed according to speed limitations. Accepted solution for this situation was discarding top and bottom 5% of the data for each evaluated group as to minimalize the effect of this noise on further evaluation.

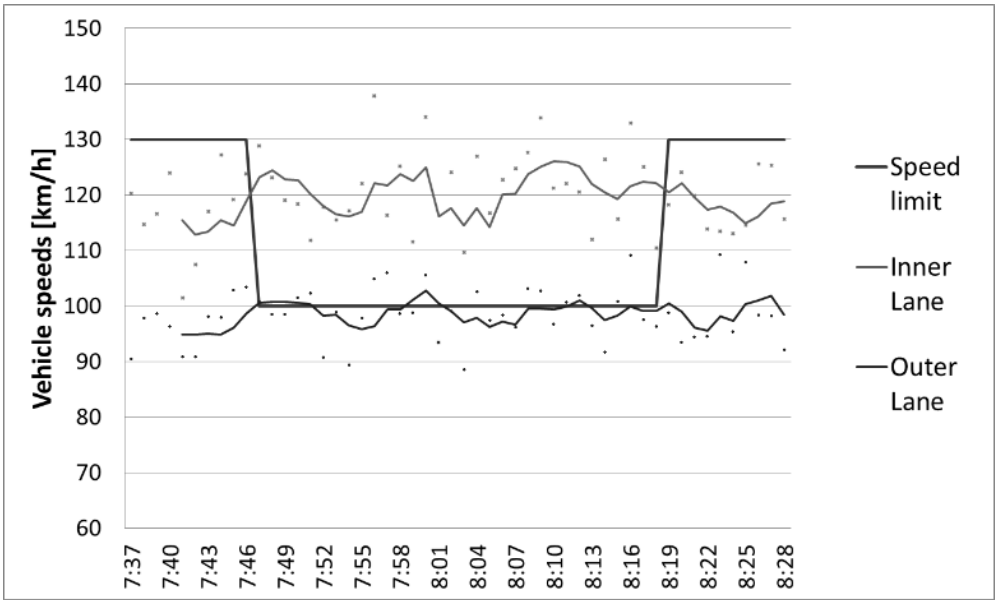
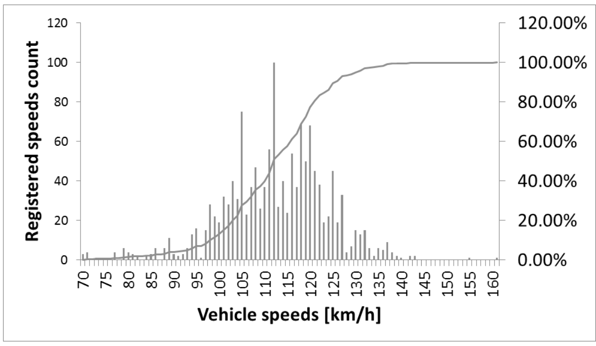


Fig. 2. Speed diagram presenting average speed of vehicles on two lanes and imposed VSL
Rys. 2. Diagram prędkości przedstawiający wartość średnią prędkości pojazdów oraz wskazania VSL

4.1. Evaluation through average values and standard deviation

Additionally we looked at the main statistical values such as average speeds and standard deviations for different speed limits within each category. These values are presented in tables 1 and 2.



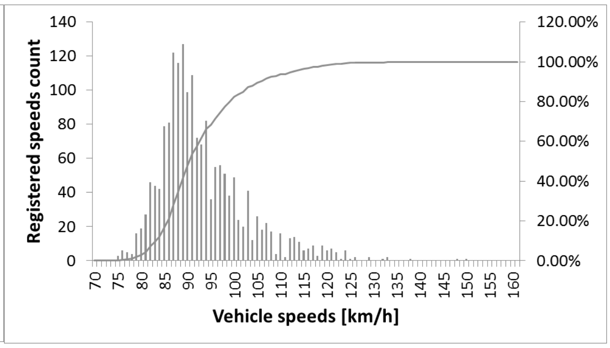


Fig. 3 and 4. Histograms of speeds at category A (DAY) and B (NIGHT) respectively, with speed limit 130 in respectively inner and outer traffic lane
Rys. 3 i 4. Histogram prędkości w kategoriach kolejno A (DZIEŃ) oraz B (NOC), przy ograniczeniu prędkości do 130 km/h na pasach odpowiednio lewym i prawym

Surprisingly, the results in tables 1 and 2 clearly state that imposing the speed limit of 120 km/h leads for the fast lane (increase from 112.21 km/h to 113.16 km/h) as well as slow lane (increase from 94.49 km/h to 98.05 km/h) to an increase in the measured average speed.

This behavior could be caused by migration of faster travelling drivers (also referred to as aggressive drivers [8]) from left lane to the right lane after implementation of new speed limit. These drivers slow down, but still increase the average speed in the right lane. Smaller number of drivers in the left lane allows the remaining vehicles to accelerate with no vehicle obstacles on their way.

This behavior was somewhat surprising but understandable. The main expected effect of VMS is however in harmonization of speed. This means, that even when the average value is higher, the standard deviation of speeds should be lower (vehicles should be driving at similar speeds due to the VMS).

The results however demonstrate that when imposing the speed limit of 120 km/h during the day, the speed deviation increases from 8.56 km/h to 10.72 km/h for the left lane and from 6.16 km/h to 6.77 km/h for the right lane.

This suggests that VMS actually leads to reduction of speed harmonization.

The effect of speed harmonization is visible mainly during the night hours (Fig 5), probably due to higher awareness of the drivers and lower level of confidence. As visibility is strongly limited, drivers do not estimate their skills as high and hence are more willing to adjust their speed. The fact that this behavior is not so visible in following speed allowance reductions may be connected with the order of displaying of the limits. Level of 120 km/h is always put as the mid-level, the first after no limitation and before stronger limits. This causes that it is first reduction visible for drivers and drags their attraction and attentiveness far more than further restrictions. Moreover restrictions of 100 and 80 may be perceived by some drivers as to strict to obey in the free flow conditions. Also described migration of the vehicles from left to right lane is not as visible as during the night left lane is hardly occupied, while most of the vehicles are travelling on right lane already (only 21% of all traffic stream is located in left lane during the night hours).

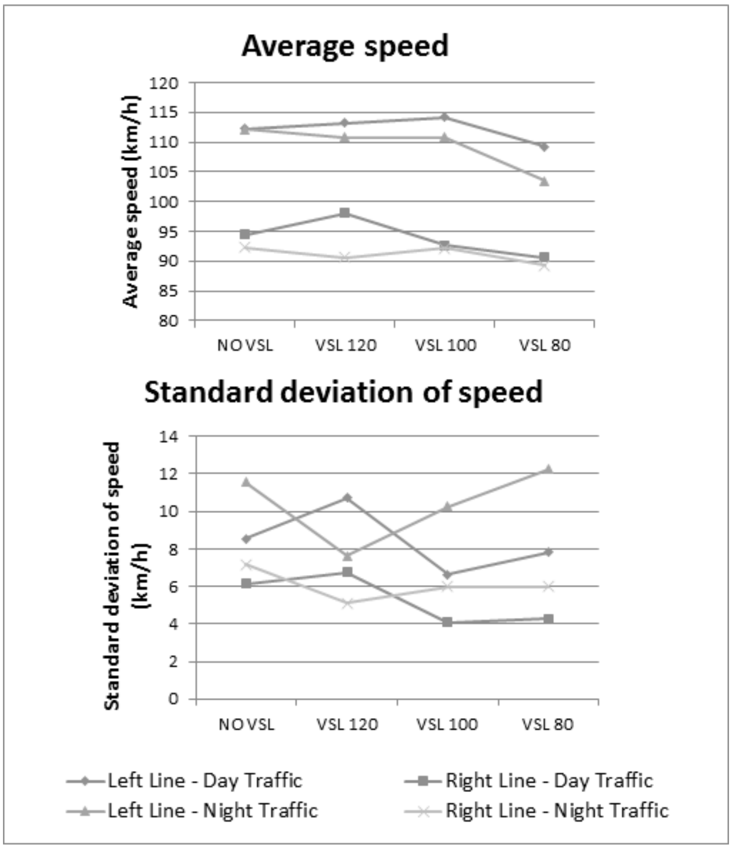


Fig. 5. Diagrams presenting Average speeds and their variances for both lanes in day and night conditions

Rys. 5. Diagramy prezentujące średnie prędkości oraz ich odchyłki dla obydwu pasów ruchu w ciągu dnia i w nocy

4.2. Evaluation through hypothesis testing

In order to be able to justify these findings, a statistical hypothesis testing was used.

Hypothesis testing is a systematic way to test claims or ideas about a group or population. In testing of research hypothesis when we know the mean and standard deviation in a single population, we can use the one–independent sample *z* test [9]. First, we state the null hypothesis H_0 as well as an alternative hypothesis H_A as *not equal to* (≠) the null hypothesis. For this test, we will place the level of significance in both tails of the sampling distribution. We are therefore interested in any alternative from the null hypothesis. This is the most common alternative hypothesis tested in behavioral science. In our case two hypothesis were stated for two different testing where first is as follows:

H_0: The VSL system influences the average driving speed.

H_1: The VSL system does not influence the average driving speeds

And it describes 2 –tailed hypothesis testing as described above. Second testing performed was 1 –tailed hypothesis testing only changes in one specified direction, which means if our VSL have imposed change of drivers speeds in predefined direction (only raised or only lowered). How the decision was made, about "direction" of testing is described during description of results. Second, the level of significance which is the controlling condition for our decision is estimated. The criterion is the likelihood of selecting a given sample mean from the population. As in most of the behavioral studies, the level of significance was set at 5% which means that we reject the null hypothesis if selecting of given sample mean is less likely than 5%. The power or sensitivity was calculated for analysed data at level of over 0.95 for each examined case. This express the probability that it correctly rejects the null hypothesis (H_0) when the alternative hypothesis (H_1) is true. It can be equivalently thought of as the probability of correctly accepting the alternative hypothesis (H_1) when it is true - that is, the ability of a test to detect an effect, if the effect actually exists [9].

Statistical hypothesis testing is based on normal sample distribution, which tells us that if the null hypothesis is true, for 5% significance level the sample mean will be equal or different for less than about two sample deviations than population mean.

To determine the likelihood of measuring the tested sample out of investigated population, the z-test statistics is used [10]. These statistics are calculating how many standard deviations, a calculated sample mean is located from the population mean. To achieve that the standard deviations as presented below in (1) and z-test statistic (2) were calculated for each case as follows:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2} \tag{1}$$

where N is number of samples, x_i are individual values of samples and μ is mean value of samples. Second calculated value is z-test statistic presented below (2). It simply describes the distance of our sample from population mean in terms of standard deviations. In other words, how many standard deviations away is our sample mean located from our population mean if put on normal distribution histogram.

$$z = \frac{M-\mu}{\sigma} \tag{2}$$

where (M) is mean of population to which we are referring in our hypothesis, μ is the mean of our tested sample and σ stands for standard deviation within the sample. Using results for Z value, the probability values, P, were calculated in Microsoft Excel SW using NORMDIST(z) function that calculates probability from (3) using values described above. This probability is directly describing likelihood of randomly measuring our sample mean from population mean with no change of external conditions.

$$f(z) = \frac{1}{\sqrt{2\pi\sigma}} e^{-(\frac{z^2}{2})} \tag{3}$$

Based on the equations provided above, the results are displayed in fig. 1 and 2. "Z value" represents the value for z-test (distance expressed by number of standard deviations from mean value), and P values represents probability for occurring such a result in examined population for 2 tailed and 1 tailed test accordingly. In 2 tailed test we check how probable is, that calculated sample value is the same as measured population (control) value, while 1 tailed test examines sample difference from population average in one direction. In other words if sample is either smaller or larger than population but not *any different* at the same time. Furthermore in table 1 the tested direction of changes for 1 tailed P value (smaller/larger) is chosen as lowering or rising of average speed with respect to the value of control population – NO VSL state. According to our accepted significance level (5%) we accept the null hypothesis if the results of our p tests are larger than 0.05 (5%), and reject it while it is lower than 0.05. In case of 1 –tailed test, rejection means that with confidence of over 95% we can say that tested sample mean has been effected by examined external factor. On the other hand, in case of 2 –tailed hypothesis rejection means that examined sample mean is changed in one predefined by us direction due to external changes.

5. RESULTS

The detailed results of hypothesis testing are included in tables 1 and 2 (always lower part, for left and right lane).

For each imposed speed limit, we test the null hypothesis, that the current speed limit causes change in the average speed measured in the section. In all cases the data for particular speed limit (i.e. 120 km/h, 100 km/h and 80 km/h) are compared to the situation without speed limit (NO VSL).

Unfortunately, the control algorithms react to the traffic in a way that the speed limit of 100 km/h is typically quickly changed to 80 km/h resp. 120 km/h. It is not a very stable state. For this reason, the number of samples in this category is not sufficient to run the hypothesis testing (denoted N/A in the tables 1 and 2).

The results clearly confirm that in any case, we are not able to reject the null hypothesis H_0. This is true for 2-tailed as well as 1-tailed tests.

We can add the fact, that the defensive drivers that are more willing to obey traffic rules, do slow down and move to the right traffic lane. In consequence of this action, speed variance in both lanes is actually increased due to new vehicles that have just started to adjust their speed, and at inner lane agresive, fast drivers see chance to go even faster than they did before as lane has less obstacles now in front of them.

This result is actually very alarming, since it goes against the main reasons for installing a highway management system, the speed harmonization.

Table 1

Calculated values for low intensity traffic stream during the day

Day Traffic		Left Lane			
	Speed limit	NO VSL	VSL 120	VSL 100	VSL 80
	Number of samples	1259	186	15	690
	Average speeds (km/h)	112.2	113.2	114.2	109.2
	St. dev. of speeds (km/h)	8.56	10.72	6.64	7.81
	Z value	-	-0.0883	N/A	-0.3800
	P - 2 tailed	-	0.9296	N/A	0.7039
	P - 1 tailed	-	0.8237	N/A	0.3520
		Right Lane			
	Speed limit	NO VSL	VSL 120	VSL 100	VSL 80
	Number of samples	3643	1157	47	2140
	Average speeds (km/h)	94.5	98	92.7	90.7
	St. dev. of speeds (km/h)	6.16	6.77	4.09	4.29
	Z value	-	-0.5257	N/A	-0.8907
	P - 2 tailed	-	0.5991	N/A	0.3731
	P - 1 tailed	-	0.2995	N/A	0.1866

This behaviour cannot be confirmed during night hours as drivers traveling at worse visual conditions tend to lose their confidence and are more likely to adjust their speed according to the speed limits.

Large contribution to the decrease of speed variance at 100 km/h during the night hours is due to the higher number of truck drivers. This was not further analysed within the hypothesis testing, but the number of trucks increases from average of 25.4% during the day to 38.9% in the night hours. In case the VSL is equal to 100 km/h, the trucks driving at about the same speed actually improve the perception of the traffic flow.

Table 2

Calculated values for low intensity traffic stream during the night

Night Traffic		Left Lane			
	Speed limit	NO VSL	VSL 120	VSL 100	VSL 80
	Number of samples	240.00	22.00	7.00	78.00
	Average speeds (km/h)	112.10	110.80	110.80	103.50
	St. dev. of speeds (km/h)	11.54	7.63	10.27	12.26
	Z value	-	N/A	N/A	-0.6992
	P - 2 tailed	-	N/A	N/A	0.4844
	P - 1 tailed	-	N/A	N/A	0.2422
		Right Lane			
	Speed limit	NO VSL	VSL 120	VSL 100	VSL 80
	Number of samples	1607.00	265.00	82.00	735.00
	Average speeds (km/h)	92.30	90.60	92.20	89.30
	St. dev. of speeds (km/h)	7.17	5.11	6.01	6.01
	Z value	-	-0.3319	N/A	-0.2186
	P - 2 tailed	-	0.7400	N/A	0.8269
	P - 1 tailed	-	0.3700	N/A	0.4135

For the category speed limit equal to 80 km/h we can observe no signifficant change of speed standard deviations, for the day hours. but for night hours there is increase present. This may be caused by the truck drivers mentioned above, but also may be simply observed by personal car drivers as to low limit to obey within low traffic at night conditions and without any participations.

Values depicted in Tab. 1 and 2 confirm the theory about migration of the vehicles during 100 km/h VSL activated during the low intensity traffic as well as shows smaller differences in vehicle speeds during high traffic volume at all cases for high volume traffic. Both, average speeds and statistical hypothesis testing shows the best efficiency of the VSL system in case of implementing 80 km/h limitation during the day, especially at high intensity traffic.

6. CONCLUSIONS AND DISCUSSION

In this paper, the drivers compliance to a Variable Speed Limit system was evaluated, at level of whole traffic stream. The data from a real installation on the Prague city ring were used for the analysis. In the analyzed sample already the measured average speeds increased during a change from no speed control to the speed limit of 120 km/h. Even more alarming was the fact that after control action, the standard deviations of speed increased as well. Moreover analysis of proportions of traffic volume in outer and inner lane at different speed limits implemented, suggests that those of the drivers that decide to obey limitation, usually move into the right traffic lane and in consequence of this behavior, inner lane drivers travel even faster than before. This is due to the fewer "obstacles" meaning slower drivers, and it causes the reduction of speed harmonization mentioned in chapter 4.1, which is a very dangerous phenomenon in light of traffic safety.

In order to confirm first findings, the authors performed a statistical hypothesis test. These tests confirmed, that on the significance level of 95 % it is not possible to confirm the null hypothesis, that the VSL system influences the average speed of the traffic flow.

Such conclusions are rather alarming, but cannot be simply generalized. One of reasons for the results obtained for the data from the Prague city ring is the absence of any automated enforcement system. Such system together with better marketing and educational campaign could increase drivers reliance on the systems which would improve their compliance. This is for example a common practice on highways in Germany and it has a positive effect on the compliance of drivers. Situation as it is now, causes some drivers to disobey implemented speed limitations and thus continuing travelling with higher speed. Another aspect that needs to be considered is the cultural and social influence on the drivers behavior. Authors believe that the driving style and obeying of speed limits may be influences by those factors.

The authors will continue to study drivers compliance to speed limits. The results of this paper clearly stress the importance of better understanding of drivers behavior with respect to the VSL systems, their compliance level and namely their trust into the system. Next, experiments measuring behavior of individual drivers (i.e. not the aggregated characteristics of the traffic flow) will be conducted to gain more insight about the motivation of different drivers types.

References

1. Beneš, J. & Přibyl, O. Effects of highway management on traffic flow characteristics. *Archives of Transport System Telematics*. 2014. Vol. 7. No. 2. P. 14-18. ISSN 1899-8208.
2. Allaby, P. & Hellinga, B. & Bullock, M. Variable speed limits: safety and operational impacts of a candidate control strategy for freeway operations. *IEEE Transactions on Intelligent Transport Systems*. December 2007. Vol. 8. No. 4. P. 671-680.
3. Hellinga, B. & Mandelzys, M. Impact of driver compliance on the safety and operational impacts of freeway variable speed limit systems. *Journal of Transportation Engineering*. April 2011. Vol. 137. No. 4. P. 260–268.
4. Abdel-Aty, M. & Dilmore, J. & Dhindsa, A. Evaluation of variable speed limits for real-time freeway safety improvement. *Accident Analysis & Prevention*. March 2006. Vol. 38. No. 2. P. 335-345.
5. Papageorgiou, M. & Kosmatopoulos, E. & Papamichail, I. Effects of variable speed limits on motorway traffic flow. *Transportation Research Record*. National Academy of Sciences. 2008. P. 37-48. ISSN: 0361-1981.
6. Yu, R. & Abdel-Aty, M. An optimal variable speed limits system to ameliorate traffic safety risk. *Transportation Research Part C 46*. 2014. P. 235-246.
7. Rämä, P. & Luoma, J. & Harjula, V. *Distraction due to variable speed limits.* Traffic Engineering + Controll. 1999. Vol. 41.
8. Krchova, Z. Aggressive behaviour of drivers in Slovakia affecting road safety. *Transport Problems*. 2012. Vol. 7. No. 2. P. 111-116. ISSN 1896-0596.
9. Dupont, W.D. & Plummer, W.D. Power and Sample Size Calculations for Studies Involving Linear Regression. *Controlled Clinical Trials*. 1998. Vol. 19. P. 589-601.
10. Privitera, G.J. *Statistics for the behavioural sciences*. Second edition. SAGE Publications Inc. 2015.

Received 12.07.2014; accepted in revised form 03.03.2016