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Impact of speed limit method on motorway safety

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Scientific paper - Preliminary report

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Impact of speed limit method on motorway safety

Results obtained during the study of various speed limit methods, including uniform, differential, and lane-based methods, are presented in this paper. The results show that the LBSL strategy is by 20 % better than other methods when safety is considered, while its traffic performance is by almost 16 % lower compared to other methods. The results also show that traffic performance decreases approximately by 19 %, but safety increases roughly by 20 %, if the speed limit is reduced from 130 km/h to 100 km/h.

Ključne riječi:
motorway safety, road network, performance, simulation, VISSIM, SSAM

Prethodno priopćenje

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Utjecaj primjene metode ograničenja brzine na sigurnost autocesta

U radu su prikazani rezultati ispitivanja primjene različitih metoda ograničenja brzine: jednolike, diferencijalne i metode pojedinačnog prometnog traka. Rezultati pokazuju da metoda LBSL ima 20 % bolje rezultate od ostalih metoda s obzirom na kriterij sigurnosti, no za kriterij prometne učinkovitosti rezultati su 16 % slabiji od rezultata ostalih metoda. Štoviše, rezultati pokazuju da su zbog smanjenja dopuštene brzine sa 130 km/h na 100 km/h, prometni pokazatelji lošiji za 19 %, no sigurnost autoceste je povećana 20 %.

Ključne riječi:
sigurnost autocesta, cestovna mreža, učinkovitost, simulacija, VISSIM, SSAM

Vorherige Mitteilung

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Einfluss von Methoden der Geschwindigkeitsbegrenzung auf die Sicherheit von Autobahnen

In dieser Arbeit werden die Resultate von Untersuchungen zur Anwendung verschiedener Methoden der Geschwindigkeitsbegrenzung dargestellt: einheitlicher und differentieller Methoden, sowie Methoden einzelner Fahrbahnen. Die Resultate zeigen, dass LBSL Methoden eine 20 % bessere Auswirkung im Vergleich zu anderen Methoden bezüglich Sicherheitskriterien haben, aber hinsichtlich Kriterien der Verkehrseffizienz 16 % schlechter abschneiden. Darüber hinaus zeigen die Resultate, dass durch ein Abmindern der Höchstgeschwindigkeit von 130 km/h auf 100 km/h die Verkehrsparameter 19 % schlechter werden, die Sicherheit der Autobahn aber um 20% ansteigt.

Ključne riječi:
Sicherheit von Autobahnen, Straßennetz, Effizienz, Simulation, VISSIM, SSAM

1. Introduction

The terms road safety and road network performance play a crucial role in each and every kind of road. The assurance of transportation safety has become even more important with an increase in road facilities such as freeways, and with rapid development in transportation technologies. Due to high cost of accidents, speed limits and related strategies have become important topics, particularly when regarded as factors affecting safety. A number of researchers, such as Evans [1] and Elvik [2], claim that speed is the single most contributing factor affecting the frequency and severity of highway accidents. Amir H. Ghods et al (2012) have defined two main speed limit strategies including the uniform speed limit (USL) and differential speed limit (DSL), based on the size, weight, and manoeuvrability characteristics of cars and trucks. [3]. In the USL strategy, all vehicles regardless of their type (light and heavy), have the same speed limit, whereas in the DSL strategy, different vehicles have different speed limits. Naturally, the speed limit for heavy vehicles is lower than that for light vehicles (Figure 1).

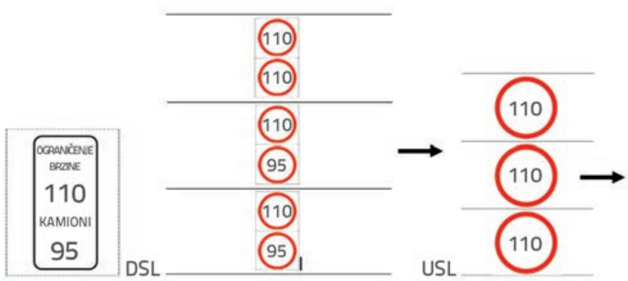

Figure 1. Vehicle-based speed limit strategies such as (DSL, USL). (speed limits expressed in km/h)

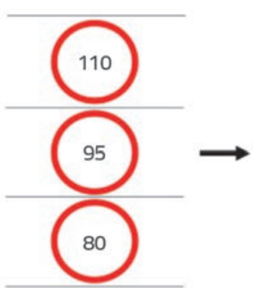

Figure 2. Lane based speed limit (LBSL), expressed in km/h

The DSL normally sets the maximum speeds for trucks in such a way that they are by about 10–15 km/h lower than the speed limits for cars in the same conditions. For instance, in Michigan the posted speed limit for trucks is by 16 km/h (10 mph, mph = miles per hour) lower than that applied for cars (95 versus 110 km/h, respectively) on rural interstate highways [4]. Thus, these speed limit strategies were categorized as vehicle-based (VB) strategies. Another speed limit strategy, totally different and known as the lane-based speed limit (LBSL), is practiced in some countries, like Iran. In LBSL, the speed limit is different at different lanes rather than for different vehicles. As a matter of fact, each lane has its own speed limit which increases from the right-side lane to the left-side one, and is equal for all vehicles, regardless of their type (light and heavy) (Figure 2).

Some studies focus on traffic performance versus safety effects of the speed limit strategies (USL & DSL). Freedman and Williams have studied traffic performance when the DSL approach was implemented. They analysed speed data collected from 54 sites in 11 North-eastern States of the USA, and determined the effects of DSL on the mean and 85th percentile speeds [5]. Their studies revealed results that are similar to those obtained by Harkey and Mera, who established that there is no significant difference between the passenger car and truck mean speeds and 85th percentile speeds when comparing USLs and DSLs [6, 7].

In safety impacts based studies, Harkey and Mera have found no significant differences between car speed variances at the USL and DSL implementation sections [7]. However, Council et al. have established that rear-end collisions between cars and trucks increase severity of crashes, at a high speed freeway with the DSL strategy [8]. An evaluation conducted by the Idaho Department of Transportation shows that changing the strategy from the USL to DSL does not bring about an increase in crashes [9]. However, there is some evidence showing that the DSL can cause an increase in some types of crashes while reducing others [6].

A study conducted by Garber and Gadiraju shows that crash rates, with an increase in posted speed limit for trucks to up to 105 km/h (65 mph), in the adjacent states of Virginia (DSL implementation site) and West Virginia (USL implementation site), do not result in a significant increase in fatal injuries and overall accident rates. In most transportation agencies, the DSL control strategies tend to be discretionary, inherently depending on agreement among various drivers taking part in the traffic stream (cars as well as trucks) [10]. Solomon found the U-shaped relationship between the crash involvement rate and the amount of deviation from average speed. An increase in speed variance may lead to an increase in the number of accidents, especially accidents involving (noncompliant) cars and (compliant) trucks [11].

The safety results of differential speed limits among cars and trucks have not been akin in previous studies. Some studies found no difference between the USL and DSL [7, 9, 10], while other studies found that one or the other policy is better [5, 8]. Most of these studies related to the impact of DSL on road safety have been adopted from statistical before-and-after approaches. One of major deficiencies of the statistical approach lies in the limitations allocated to the analysis because of the available data [3]. Thus the use of microscopic traffic simulation platforms in conjunction with surrogate safety measures would provide an alternative approach for safety implication evaluation of uniform and differential speed limits [3]. Saccomanno et al. [12] discussed advantages of this approach in their study of

the DSL and maximum speed limit (MSL) (differential speed controls with truck speed limiters) strategies applied to freeway segments.
In this study, the safety and traffic performance impacts of the LBSL and VB (including USL and DSL) strategies are analysed for freeways, under similar laboratory circumstances, using the VISSIM traffic simulation software package. This study claims to be of prime importance, because no study has previously been made on the comparison between these two kinds of speed limits strategies (VB, LBSL).

2. Simulation model for freeway

The effect of individual-vehicle interactions is the result of a complex process that can only be captured using simulation, and cannot be explained by a simple analytic process [3]. Thus a microscopic traffic simulation was conducted in this study using the VISSIM software. Each vehicle's behaviour in the simulated network was analysed sporadically, while they all relied on a simulated network environment. The response of each vehicle was considered as a result of interactions between many users and vehicles present in the network. Results were significantly affected by details used in the model [13]. Any changes in the car following lane changing and lateral spacing models can significantly affect the traffic and safety outputs of the simulation model. Shaykh al-slami et al (2011) and Safarzadeh et al (2010) described the VISSIM models and their underlying mathematical expressions and calibration results [14, 15]. Four individual traffic performance criteria and five individual safety criteria were considered in this study, in order to evaluate traffic performance and safety. The traffic performance criteria were evaluated in two positions. The first one was located in the middle of the basic section (first part), and the second one was located in the middle of the weaving section. These sections are marked with red coloured circle signs in Figure 3. Traffic performance criteria were: speed difference between various lanes in two sections, lane utilization in two sections, travel time per kilometre, and average speed in the network.

Figure 3. Case study freeway segments

Vehicle trajectories, extracted from VISSIM simulation models results, were used for traffic safety evaluation, which was based on traffic conflict analysis. Traffic conflict analysis is a safety analysis method that uses non-crash data. It is based on observations of individual vehicle movements, and on identification of situations that can result in critical incidents. Critical incidents are serious incidents that may result in a crash. They are characterized by sudden braking, sudden change of lane, or steering off the road [16]. Parker and Zegeer defined a traffic conflict as an event involving the interactions of at least two vehicles where at least one takes evasive actions to avoid an imminent collision. The danger was caused by a leading vehicle that reduces speed abruptly or changes lane to cut the following vehicle. They elaborated this definition in which a conflict occurred when the vehicles were on a collision course i.e., vehicles attempted to occupy the same space at the same time [17]. The advantage of using the conflict analysis on crashes is the possibility of examining even the near-crash events that are not available in the crash report information. These events occur more frequently than crashes and their prior information is the same as that of crashes [18].
To evaluate a comprehensive scrutiny, other criteria such as (PET, MaxS, DeltaS, DeltaV and MaxDeltaV) were considered in addition to the Time-to-Collision (TTC), which is defined as the ratio of relative speed of vehicles to their relative positions (Equation 1),.

$$TTC = \frac{X_i - X_{i+1} - L_i}{V_{i+1} - V_i} \tag{1}$$

Here, X_i and X_{i+1} are positions of two successive vehicles and V_i and V_{i+1} are their velocities; and L_i is the length of the first vehicle. PET is the time difference between the first vehicle's last occupied position and the second vehicle's arrival to the same position. A value of 0 indicates an actual collision [14]. MaxS is the maximum speed of any vehicle throughout the conflict. DeltaS is defined as the magnitude of the difference in vehicle velocities (or trajectories), DeltaS = | v1 - v2 |. MaxDeltaV is the maximum DeltaV value of any vehicle in the conflict [19].

3. Simulation variables

A case study simulation was carried out for a six-kilometre segment of a multi-lane freeway, as illustrated in Figure 3. The first kilometre was considered as the warm-up zone and was not included in the simulation results. The simulation time was taken to be 70 minutes, including a 10-min warm-up interval. On an average, 10 runs were carried out for each speed control strategy (USL, DSL, and LBSL). In the simulation, the input traffic flow varied from 3750 to 9000 vph (vph - vehicle per hour) and the trucks participated with 10 to 15 percent in the traffic. In the USL strategy, all vehicles had the same speed limit regardless of their types and the lane of crossing, whereas in the DSL strategy the car and truck maximum posted speed differences were set to 15 km/h. As the Iranian traffic organization regulated the corresponding differential speed in the LBSL strategy, the maximum posted speed differences between vehicles (cars & trucks) in each lane amounted to 15 km/h in this strategy. Thus in the LBSL strategy simulation, if in simulation the number of lanes is 3 and the maximum posted speed limit is 100 km/h, the posted speed limit for each of the individual lanes from the left lane to the right line will be 100, 85, and 60 km/h, respectively. It should be noted that the maximum posted speed

Table 1. Studied parameters and scenarios

Symbol	Explanation	Unit	Values	Variants
L	Distance between on- ramp and off-ramp	[m]	650 i 850	2
N	Number of lanes in basic freeway	-	3 i 4	2
V1	Input volume in basic freeway	[veh/h per each lane]	750, 1250 i 1750	3
V2	Input volume in on-ramp	[veh/h]	1500 i 2000	2
T	Heavy vehicle percentage	[%]	10 i 15	2
Sc	Speed limit scenarios	-	USL, DSL i LBSL	3
SL	Maximum posted speed limits	[km/h]	100, 110, 120 i 130	4
			Number of the whole scenarios	576

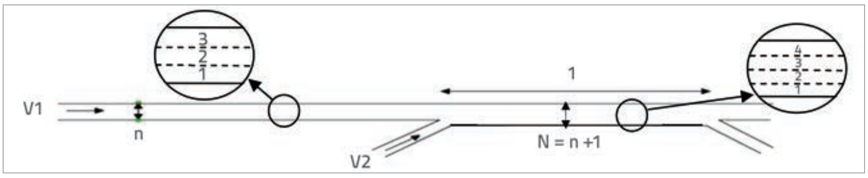

Figure 4. Parameters that are entered in model

weaving section, L = 650 m. Four and five lanes were considered for the research model. Lane 1 is labelled for the last lane situated at the right-side section of the freeway for the corresponding direction.

limits assumed in simulation models have been obeyed by 85 percent of drivers. As shown in Figure 4, the number of lanes is geometrically different in the basic and weaving freeway sections. There is one extra lane in the weaving section that is related to the basic freeway section.

In this study, some important parameters were chosen for the analysis, and various values were assigned to each parameter. A total of 576 scenarios were considered in this study. The figures for analysis resulted from multiplication of variants shown in the last column of Table 1. Some of these are illustrated in Figure 4.

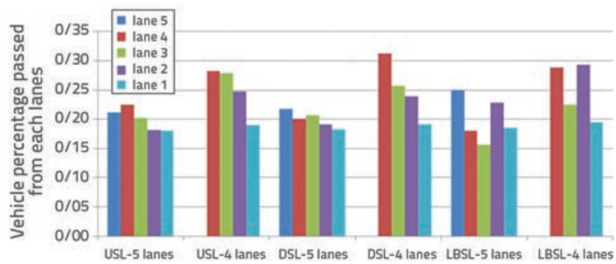

Figure 5. Lane utilization for area between on-ramp and off-ramp (In this graph, L = 650 m, V_1 = 1750 veh/h, V_2 = 2000 veh/h, T = 15 %)

4. Research model

The goal of this study was to compare different impacts of speed limit scenarios such as USL,DSL and LBSL at maximum speeds limits (such as 100, 110, 120, and 130 km/h) on the network performance and safety. Probable differences between speed limit scenarios were thus examined. According to this, one criterion out of nine (4 traffic performance & 5 safety) was selected as target, as illustrated in graph form in figures 5 to 12. The difference between strategies was studied by comparing variations in each graph based on the corresponding criterion. Finally, the statistical Analysis Of Variance (ANOVA) was used for quantitative verification of results.

4.1. Lane Utilization for area between on-ramp and off-ramp

The lane utilization after devising different strategies with varying number of lanes between on-ramp and off-ramp is compared in Figure 5. The constrained flow does not occur when the length between these two is as far as the critical length, L = 850 m. However, the constrained flow does occur in

It can be inferred from Figure 5 that the lane occupation decreased from the last lane to lane 1. The difference in usage between the first and the last lane in 4-lane section roads was even greater compared to 5-lane roads. An extraordinary use of the second lane was also observed in the LBSL strategy. The speed arrangement in the LBSL approach, which was different from other approaches, justified this extraordinary use in the second lane. It means that some of the drivers who tend to enter or exit the freeway, are more inclined to use a lane with a higher speed limit to move faster. Results show that the LBSL creates more lane changes in this area, and may bring about deterioration of safety conditions. Also, the LBSL strategy leads to the creeping movement of vehicles in the second lane, which was a boundary of change for vehicles moving from outer lanes toward the first lane and vice versa. This by itself can cause an increase in the proportion of the second lane use, which means that the percentage of crossing vehicles in this lane is higher compared to other lanes.

4.2. Lane Utilization in basic freeway segment

The percentage of use of each lane after implementation of various strategies in the basic freeway section with three or four lanes is compared in Figure 6. Here, lane 1 is labelled for the last lane situated at right-side section of the freeway for the corresponding direction.

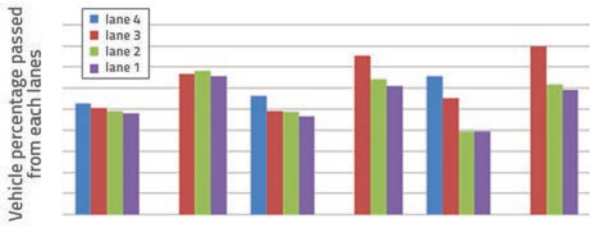

Figure 6. Lane utilization in basic freeway section (In this graph, L = 650 m, V_1 = 1750 veh/h per lane, V_2 = 2000 veh/h, T = 15 %)

According to Figure 6, the USL to LBSL Strategies, which were implemented for the three-lane or four-lane basic freeway sections, show that the lane usage increased from the first lane (lane 1) toward the last lane. Two reasons should be given to explain this trend. The first one is that drivers tend to do and finish their travel as soon as possible (car following model combined to lane changing model find the opportunity for each vehicles independently to pass the other vehicles to ascertain it). As shown in Figure 7 (from USL to LBSL), the second reason is that the speed differences from the first lane (lane 1) to the last one naturally increase because the drivers tend to move to the fastest lane (last lane). Also it can be derived that the LBSL strategy increases congestion in the high-speed lanes (i.e. lane 3 in a 3-lane freeway, and lane 4 in a 4-lane freeway) of the basic freeway section, and also that the overtaking potential declines with an increase in the possibility of overtaking from the right side of each vehicle. Hence, it was expected that the number of lane changes in the LBSL strategy is greater compared to the other two strategies. The amount of this measure was not related to the changes in length between the entrance and exit ramps, the number of lanes, and the percentage of heavy vehicles, but was related to speed limit scenarios. It can be claimed that the USL and DSL strategies were not different considering the percentage of traffic passing via the basic freeway section, while these strategies both differed from the LBSL strategy.

4.3. Speed difference between various lanes in basic freeway section and area between on-ramp and off-ramp

Speed differences between each of the individual lanes, after implementation of various speed limit strategies, are compared in Figures 7 and 8. Thus, the maximum number of speed differences between all vehicles that used a particular lane is shown in this graph.

After analysis of figures, it was established that speed variances between various lanes in the basic section, and also between the on-ramp and off-ramp segments, were identical in the USL and DSL scenarios, but were completely different from LBSL scenario; here, the speed variance was much higher compared to other scenarios. In the basic section, speed variances were lower compared to the one between the on-ramp and off-ramp. It can be concluded that the strategy with more unity produces more speed driving but the speed differences between each lane are lower, and so the USL has the best traffic performance and mobility, while the LBSL is characterized by greater disturbance in the traffic flow.

Speed differences between the on-ramp and off-ramp sections are compared in Figure 7, whereas the same factor for the basic freeway section is compared in Figure 8. Horizontal axes are V_1+V_2 in Figures 7 to 12.

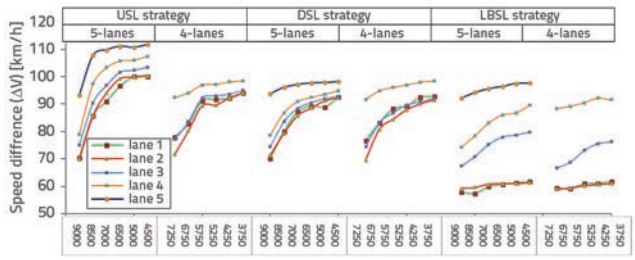

Figure 7. Speed difference between various lanes in the area between on-ramp and off-ramp (in this graph, L = 650 m, M.S.L = 120 km/h, T = 15 %)

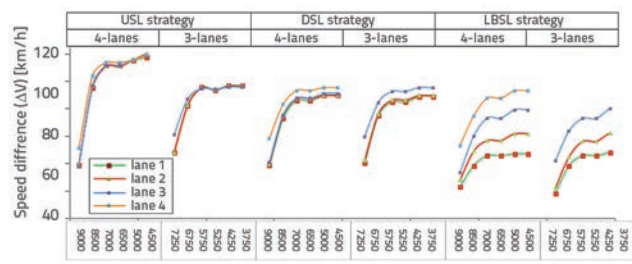

Figure 8. Speed difference between various lanes at basic freeway section (in this graph, L = 650 m, T = 15 %)

4.4. Average speed in the network

Figure 9 shows variation in the network average speed for different strategies and for various numbers of maximum posted speed limit, which is labeled as M.S.L. (maximum speed limit).

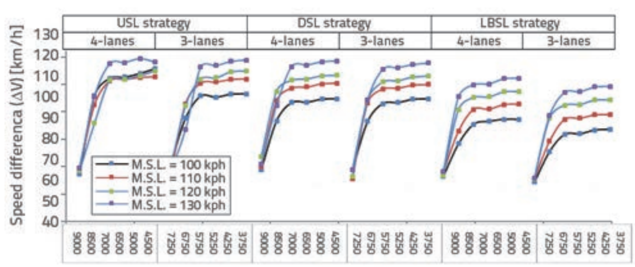

Figure 9. Average speed in network (In this graph, L = 650 m, M.S.L = 120 km/h, T = 15 %, M.S.L. maximum speed limit)

The results show that the USL and DSL are the same, but the LBSL scenario has the weakest performance with about 16 percent. Also, it is clear that, after decreasing lane numbers from 4 to 3, the performance becomes even worse. Furthermore, it can be seen that the traffic flow is more fluent and that the average speed increases with variation of some parameters such as the distance between two ramps (from 650 m to 850 m), truck percentage (20% to 1%0), and speed limit (100 km/h to 130 km/h),.

4.5. Travel time per one kilometre

The variation in travel time for each individual strategy, with different posted speed limit numbers, is presented in Figure 1.

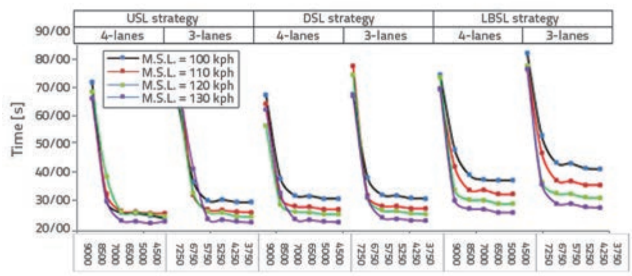

Figure 10. Travel time per one kilometre (in this graph, L = 650 m, T = 15 %)

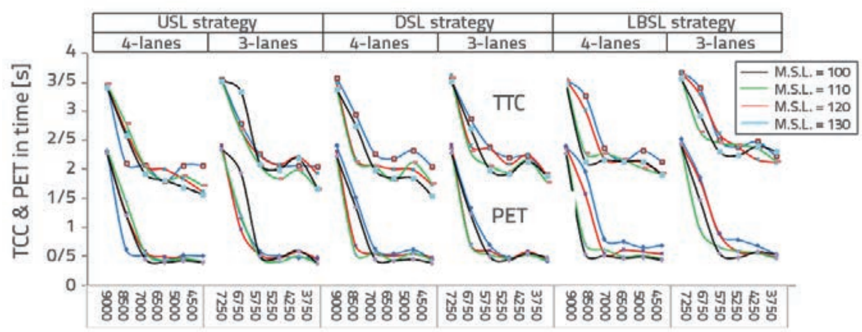

Figure 11. Safety criteria TTC and PET (in this graph, L = 650 m, M.S.L = 120 km/h, T = 15 %)

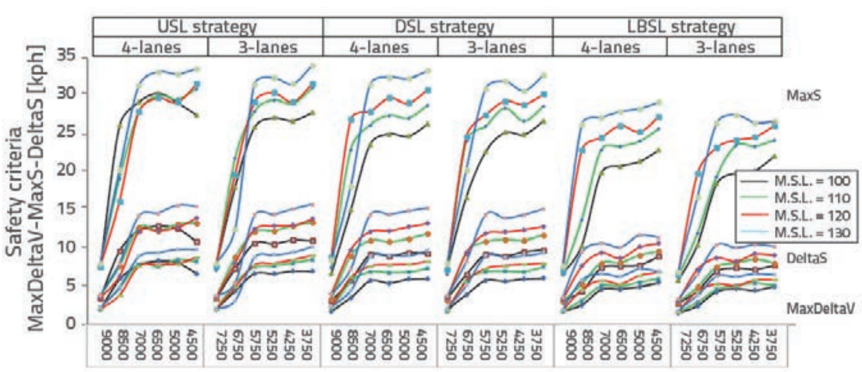

Figure 12. Safety criteria: MaxDeltaV – MaxS - DeltaS (in this graph, L = 650 m, M.S.L = 120 km/h, T = 15 %, M.S.L. maximum speed limit)

It can be seen that the USL and DSL scenarios are similar, as confirmed by statistical analysis. Furthermore, it was revealed that the LBSL scenario has the weakest performance, due to its lowest average speed. Also, the travel time reduces with an increase in maximum speed limits. As shown in Figures 9 and 10, the DSL strategy has some similarities with the USL, but the difference between the USL and LBSL is greater compared to that between the DSL and USL strategies. Consequently, the graph analysis shows that the USL and DSL strategies are approximately the same, but that they completely differ from the LBSL. It can therefore be concluded that the LBSL has the lowest traffic performance compared to all other strategies.

4.6. TTC and PET safety criteria

Safety criteria variations after implementation of different strategies are compared in Figure 11. In top series, charts are allocated to the time-to-collision (TTC) whereas in bottom series, charts are allocated to the post-encroachment-time (PET).

Unexpectedly, Graph trends and statistical analysis indicate that the LBSL strategy does not reduce the level of safety. The chart analysis and analytical calculations show that the LBSL strategy is more desirable than the other two strategies in terms of safety and performance. The LBSL strategy is more convincing than other strategies for about 15 % with respect to the TTC, and for about 24% with regard to the PET. This result was justified by a lower average speed of the entire network in the LBSL strategy, compared to other strategies. As a result, it can be expected that the LBSL strategy will have a better safety effect compared to the other two strategies. The analysis of variance shows that individual strategies are completely independent. Also, the one-way ANOVA shows that the USL and DSL strategies have the same safety effects, and that they do not greatly differ. This also confirms the results obtained in previous studies. In addition, the one-way ANOVA confirms that an increase of the maximum speed limit from 100km/h to 130 km/h, causes a decrease in the average TTC value by about 12 %, and PET by roughly 21 %. As shown by the above mentioned lane utilization parameter, the LBSL strategy creates a greater lane changing opportunity and, as this strategy increases vehicles portion in the high-speed lane (last lane) compared to other lanes, it causes a decrease in overtaking opportunity and increases the chance of illegal overtaking, which may lead to

Table 2. One-way and two-way ANOVA results

Criteria							Title	ANOVA analysis
Safety					Traffic performance			
MaxDeltaV	DeltaS	MaxS	PET	TTC	Travel time	Average speed		
0.000	0.000	0.000	0.004	0.000	0.000	0.000	Speed limit Scenarios P-Value	Two-way
IN.	IN.	IN.	IN.	IN.	IN.	IN.*	Interpretation	
0.000	0.000	0.000	.016	0.000	0.000	0.000	Maximum speed limits P-Value	
IN.	IN.	IN.	IN.	IN.	IN.	IN.	Interpretation	
0.692	0.582	0.930	0.849	0.998	0.502	0.746	Interaction P-Value	
No Interaction**	No Interaction**	No Interaction**	No Interaction**	No Interaction**	No Interaction**	No Interaction**	Interpretation	
6.477	10.463	24.222	0.774	2.298	38.12	98.92***	DSL-value	One-way for scenarios
6.829	10.985	24.828	0.781	2.270	38.02	100.08	USL-value	
4.797	7.760	19.956	0.956	2.600	44.81	84.41	LBSL- value	
4.992	8.046	19.920	0.969	2.567	44.87	83.97	100 km/h - value	One-way for maximum speed limits
5.825	9.414	22.437	0.844	2.399	40.85	92.62	110 km/h - value	
6.296	10.147	23.999	0.772	2.329	38.97	97.22	120 km/h - value	
7.024	11.337	25.651	0.764	2.270	36.57	104.06	130 km/h - value	

IN. = Independent
* Independent is used in both one-way and two-way analysis of variance when both parameters have no effect on each other (at least one of them is different).
** **: If speed limit scenarios such as the DSL, USL and LBSL and speed limits such as 100, 110, 120 and 130 km/h do not have any effect on each other, two-way analysis of variance is not necessary and the investigation of each case, such as speed limit scenarios and maximum speed limits, should be analysed independently. So, the one-way analysis of variance is adequate.
*** Best scenarios are underlined.

a higher accident hazard. It could therefore be expected that the LBSL strategy is characterized by the lowest safety level. But, as the safety criteria show, this strategy actually has the best safety conditions. It may be due to a lower speed (lower traffic performance) rather than to a higher lane changing and illegal overtaking in the traffic stream. Thus, safety conditions are much more sensitive to speed reduction compared to other parameters such as lane changing and illegal overtaking.

4.7. Different speed safety criteria variations

Variations of different speed safety criteria, including the maximum speed variation (MaxDeltaV), maximum speed (MaxS), and speed difference (DeltaS), as obtained based on various strategies, are shown in Figure 12. Top series charts are for the MaxS evaluation, middle charts are for the DeltaS evaluation, while low charts are for the MaxDeltaV evaluation.
It can be observed that the LBSL strategy had a lower (about 27 %) maximum speed variation (MaxDeltaV) compared to the other two strategies. On the other hand, speed variations would supply the mean collision acceleration. Thus, the lower the possible maximum acceleration, the lower the severity of the collision. As a result, in the total network, a decrease in maximum speed variance improved safety and driver convenience considerably. It was also found that, as the LBSL strategy was implemented, it had the lowest (about 19 %) maximum speed (MaxS) compared to other strategies. Since the maximum speed decreased in collision situations, the system was improved in terms of safety and hence collision severity was reduced remarkably. In addition, it was established that the LBSL strategy had a lower speed variation rate (about 27 %) as related to the other strategies. However, as speed variations in the system lowered, a greater homogeneity was achieved, and the safety was improved. Finally, when considering the three criteria MaxDeltaV-MaxS-DeltaS on graphs and in the scope of statistical analysis, it was found that the LBSL strategy is better in terms of safety compared to the other two strategies. The analysis of variance indicated that different strategies were independent from one another, and that there was no interaction. Also, the one-way ANOVA related to these parameters (MaxDeltaV-MaxS-DeltaS) made it clear that the USL and DSL strategies were the same in terms of safety but that they also presented slight differences. In addition, the one-way ANOVA test shows that the safety improves remarkably (roughly 30 %) for three criteria i.e. MaxDeltaV-MaxS-DeltaSon, if the maximum speed limit is reduced.

5. ANOVA test results

The analysis of variance (ANOVA) is used in order to analyse the differences between group means in order to identify whether the means of several groups are probably equal or not. So, it generalizes the t-test to more than two groups.
ANOVA is a particular form of statistical hypothesis testing heavily used in the analysis of experimental data. A statistically significant result, when a probability (p-value) is less than a threshold (significance level), justifies rejection of the null hypothesis. In this research, the null hypotheses of all the speed limit scenarios, and all the maximum speed limits, are the same [20].
In the analytical process, the interaction between two main cases such as the speed limit scenarios and maximum speed limits, is first clarified using the two-way ANOVA test. As the results show (Table 2), speed limit scenarios and maximum speed limits have no effect on each other, and they are independent. So, the one-way analysis of variance is considered adequate. Also, the two way ANOVA analysis shows that all seven criteria are independent of speed limit scenarios and maximum speed limits, because of speed limit scenarios, P-Value < 0.05, and also maximum speed limits, P–Value < 0.05, in which the significant level is 0.05 (α = 0.05) [20]. It means that, in all seven criteria, at least one of the maximum speed limits or speed limit scenarios is statistically different. For example, as shown in Table 2: "one-way for scenarios", there is no significant difference between the USL and DSL scenarios in case of all seven criteria, but the two greatly differ from the LBSL scenario as the P-Value is at the less than significant level.
As can be seen in results shown in "one-way for scenarios", the average of the "average speed" criterion in both USL and DSL statistically presents no significant change, but there is a great difference compared to the LBSL. It is obvious that the traffic performance increases with an increase in average speed in different circumstances.

6. Conclusion

Various strategies currently applied as the speed limit strategies for freeway traffic control in Iran and other countries are examined in this study. Strategies currently applied in Iran are compared with other strategies in terms of safety and freeway network performance. The VISSIM is used to compare the impact of these strategies and scenarios under a range of traffic and geometric conditions. The SSAM is also used for further in depth safety analysis. The results are compared through graphical tools and also through more quantitative statistical tools such as ANOVA. Based on the analysis, a comparison of the strategies is made in terms of safety and network performance.
The results indicate that the LBSL (lane based speed limit) strategy is less adequate in terms of performance criteria (average speed of the entire network and average travel time) when compared to the other two strategies (DSL and USL). Simulation results show that the LBSL strategy has a lower traffic performance (by about 16 %) than the other two strategies (DSL and USL). However, in terms of safety, it is preferable to the other strategies (by about 20 %). Results also indicate that the speed difference and the lane changing potential are higher in the LBSL compared to the other strategies. Nevertheless, it was established that the average speed in the LBSL strategy with the same speed limit is lower compared to the other two strategies. In terms of safety, the LBSL strategy ranks better than the other two strategies. The comparison of the effects of the USL and DSL strategies on the average speed shows that the changes in these types of strategies have a marginal effect on the average speed. This means that the differences in speed between the light and heavy vehicles do not have a significant effect on the average network speed. Considering both performance and safety, the USL and DSL strategies do not have a significant priority over one another; and it can be concluded that the main distinction is between the LBSL and VB strategies. Furthermore, results show that traffic performance decreases by approximately 19 %, whereas safety increases by approximately 20 %, with the reduction in speed limit strategies from 130 km/h to 100 km/h.

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