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Speed behaviour in work zone crossovers. A driving simulator study

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ABSTRACT

Reductions in speed and, more critically, in speed variability between vehicles are considered an important factor to reduce crash risk in work zones. This study was designed to evaluate in a virtual environment the drivers' behaviour in response to nine different configurations of a motorway crossover work zone. Specifically, the speed behaviour through a typical crossover layout, designed in accordance with the Italian Ministerial Decree 10 July 2002, was compared with that of eight alternative configurations which differ in some characteristics such as the sequence of speed limits, the median opening width and the lane width. The influence of variable message signs, of channelizing devices and of perceptual treatments based on Human Factor principles were also tested. Forty-two participants drove in driving simulator scenarios while data on their speeds and decelerations were collected. The results indicated that drivers' speeds are always higher than the temporary posted speed limits for all configurations and that speeds decreases significantly only within the by-passes. However the implementation of higher speed limits, together with a wider median opening and taller channelization devices led to a greater homogeneity of the speeds adopted by the drivers. The presence of perceptual measures generally induced both the greatest homogenization of speeds and the largest reductions in mean speed values.

1. Introduction

Roadway work zones are hazardous, both for workers and motorists who travel through a complex array of signs, channelizing devices and lane changes. Improper lane changing manoeuvres and possible vehicle encroachments in the activity areas may cause injuries to both the car occupants and road workers.

Several studies agree that the presence of work zones significantly increases the risk of road crashes (Garber and Zhao, 2002; Khattak and Council, 2002; La Torre et al., 2014; Pal and Sinha, 1996; Saleh et al., 2013; Srinivasan et al., 2011; Wang et al., 1996).

Speeding is clearly a factor that contributes to traffic accidents and fatalities within work zones. Furthermore crash statistics show that rear-end accidents represent the most common crash type (Bai and Li, 2006; Garber and Zhao, 2002; Ullman et al., 2008). This generally occurs because the presence of a work zone often causes congestion and high variance in speeds. For this reason in work zone-related crashes, the analysis of the speed variance, in addition to the analysis of the mean speed, can provide more relevant information.

This paper aims to investigate drivers' speed behaviour through nine different configurations of a work zone crossover in order to identify measures leading to safer conditions for drivers. The study has been implemented in the driving simulator of the Road Safety and Accident Reconstruction Laboratory (LaSIS) of the University of Florence (Italy) and has been focused on work zone crossovers because a previous extensive accident analysis of stationary work zones identified this layout as the most critical for safety (La Torre et al., 2015).

Nine different work zone crossover configurations have been analyzed. Five of the nine configurations have been studied within the ASAP (Appropriate Speed Saves All people) project (Cocu et al., 2014), a European project funded by the Conference of European Directors of Roads (CEDR) and addressed to the issues of speed management in work zones. The remaining four configurations have been designed at a later stage and added to the driving simulation study to further implement the ASAP research findings.

2. Background

Several studies found speeding as a major factor in traffic accidents and fatalities within work zones (Bryden et al., 2000;

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Dissanayake and Akepati, 2009; Li and Bai, 2007, 2009; Garber and Zhao, 2002). A report by the Kansas State University (Dissanayake and Akepati, 2009) shows that of the 720 work zone fatalities in 2008 in U.S., speeding was a factor in 225 cases. In a study of work zone crashes in Kansas (Li and Bai, 2009), speeding was a factor in 15% of the fatal crashes and 20% of the crashes causing injuries.

Also a large speed variance may lead to higher accident rates at work zones: the relationship between travel speed and accident rates indicates that when speed differences between different vehicles increase the accident risk increases as well. (Migletz et al., 1993; Salem et al., 2006). The safest traffic flow conditions occur when all vehicles are travelling at approximately the same speed, thus when the speed variance is small. Furthermore the results show that the safest work zones are those with the smallest increase in the upstream-to-work-zone speed variance (Migletz et al., 1998).

Temporary speed limits should induce the drivers to reduce their speed. However lower speed limits do not necessarily result in a lower speed variance (Garber and Zhao, 2002; Hou et al., 2011; Migletz et al., 1998).

Within the ASAP Project, over 270 technical documents regarding methods used to manage and control the speed of vehicles in road work zones were collected and reviewed (La Torre et al., 2013). These methods can be informational measures (such as signs and flaggers), physical systems (such as rumble strips, chicanes, lane width restrictions), and enforcement (police presence, automated control). In general, all the methods discussed have some effectiveness especially if integrated with the presence of police enforcement. Some of the most effective are those related to speed monitoring and variable message signs (VMSs) where the driver is real time informed on the driving speed or on the traffic situation ahead. Police enforcement has the largest effects in term of speed reduction but only when the police presence is connected to active enforcement activities (La Torre et al., 2013).

A road work speed management procedure is traditionally organized around successive steps and may be influenced by many variables. One of these is certainly the road work layout to be implemented on the road section. A study conducted by the University of Florence (Italy) indicates that the crossover work zone represents the most critical layout for safety (La Torre et al., 2015). This result is confirmed by other researches that identified the highest accident rates in the presence of such layout (Benekohal et al., 1993; Pal and Sinha, 1996). Speed management devices, such as advanced warning trailer, speed camera sign, speed display, variable message sign (VMS), rumble strips, automatic speed camera and police car, have been tested within crossover work zones installed, as part of the ASAP project, along Czech and Belgian motorways in order to understand their effectiveness on drivers' speed (Cocu et al., 2014). ASAP data from Czech Republic indicated a good impact of a speed camera sign with a mean speed reduction of about 4 km/h. Positive effects on reducing speed were also induced by VMSs in the work zone area and by presence of a police car upstream. Results from Belgian showcases indicated a localized effect of the presence of automatic speed cameras, whereas no significant effects were recorded from other devices such as speed display and transversal rumble strips installed within the advance warning and transition areas.

In Switzerland, Spacek et al. (1999) investigated the effects of different speed limits and enforcement devices as well as the effects of various channelization devices in four different work zone crossovers. The results indicated that when travel directions were structurally separated from the work zone activity area by concrete barriers, the crash rate was roughly the same of that recorded in the situation without work zone. Furthermore the findings showed that channelization curbs caused smoother decelerations in approaching the crossover compared to the configurations with vertical delineators. The increase of the speed limit within the transition area had no significant influence on the general speed behaviour but resulted in smoother decelerations in approaching the crossover.

The evaluation of work zone safety measures by means of field tests is costly, difficult to modify, subject to environmental changes and can pose risks for safety of both test participants and researchers. Driving simulators are an effective alternative research tool allowing researchers to evaluate a wide range of interventions that cannot be implemented on site due to legislation restrictions and entailing reduced implementation costs and safer testing conditions.

An extensive literature review carried out by Bella (2009a) showed that driving simulation provides the driver with enough visual information to allow him to correctly perceive speed and distance. In particular, several experimental studies comparing on-road and simulation performance through work zones have revealed a validity of medium – high fidelity driving simulators (Bella, 2004, 2006; Bham et al., 2014; McAvoy et al., 2007).

A large amount of researches aimed at evaluating the driving behaviour in approach and within work zones have been carried out with driving simulators in the last decade (Allpress and Leland, 2010; Bella, 2009b; Gustafsson et al., 2014; McAvoy et al., 2011; Nelson et al., 2011; Sommers and McAvoy, 2013; Ullman et al., 2005, 2007). Most of these studies were aimed at evaluating the effect of different speed management systems on driving performance and focused on the analysis of mean speeds and decelerations.

In 2009, Bella conducted a study to evaluate the driver behaviour close to crossover work zones (Bella, 2009b). Driving simulations were carried out on four different work zone configurations and focused on the analysis of mean speeds and mean decelerations in response to different schemes of signalling and different work zone geometry.

The results indicated that drivers are not affected by the imposed speed limits and travel at higher speeds than that indicated on the traffic sign. The recorded mean speeds were below the limits only within the crossover area.

Not many driving simulation studies investigated the effects of these speed management systems on speed variances in the work zone area.

Nine different crossover configurations have been designed and tested in the driving simulator of the Road Safety and Accident Reconstruction Laboratory (LaSIS) of the University of Florence (Italy). Five of the nine configurations have been designed and analyzed as a contribution to the ASAP project (Cocu et al., 2014). The driving simulation experiments, performed during the ASAP project, were focused on the analysis of speed variances in addition to that of mean speeds. The experiments investigated the effects of different speed limit sequences and alternative design features, such as wider lanes and median openings.

The remaining four configurations have been designed at a later stage and added to the driving simulation study to further implement the ASAP research findings. A different approach, based on Human Factor (HF) principles for safer roads (PIARC, 2008), has been tested in such configurations. This approach consisted in manipulating the visual environment by means of different traffic calming measures to unconsciously induce motorists to moderate their speed. The considered approach is conceptually similar to those that use pavement markings, such as chevrons or transverse bars, lane narrowing width or flashing beacons whose effectiveness in reducing speeds has already been ascertained (Godley et al., 1999; Katz, 2007; Voigt and Kuchangi, 2008).

3. Material and methods

3.1. LaSIS driving simulator

The LaSIS driving simulator (University of Florence, 2013) used for the tests is a medium-high fidelity dynamic simulator, equipped with a full scale vehicle fitted on a 6° of freedom Stewart's platform, allowing roll, yaw and pitch.

The driver, inside the cabin, is immersed in a virtual environment in which all the sensorial stimuli typical of driving are faithfully reproduced. The visual reproduction of the road scenario is obtained by means of four projectors installed on the ceiling, projecting on a cylindrical screen embracing an angle wider than 200°. The three rear mirrors are replaced by 6.5" LCD monitors, reproducing the rear vision. The sound is generated by a multichannel audio system, capable to reproduce both the vehicle and the environmental noise. All the functions are supervised by a network of 5 computers, including an operator's station from which the simulation is managed.

3.2. Participants

Forty-three subjects were recruited on a voluntary basis among students, staff of the University of Florence (Italy) and other volunteers from outside the University according to the following criteria: possession of a valid Italian driver's license, with at least five years of driving experience, an annual driven distance greater than 5000 km and low susceptibility to motion sickness.

Since one subject exhibited simulator sickness and did not complete the experiment, forty-two subjects (9 women and 33 men) participated in the research. Age varied between 24 years and 50 years (mean value: 36.1 years; standard deviation: 8.2 years). Their driving experience (measured in terms of years of driving license possession) varied between 5 years and 32 years (mean value: 16.8 years; standard deviation: 7.9 years). The analysis of the influence of gender, inexperience (young drivers) and ageing (older drivers) on the driver's ability to capture the input generated by the infrastructure was outside the scope of the research.

3.3. Scenarios' design

The analyzed scenarios are based on a 2 + 2 lane motorway with a standard speed limit of 130 km/h. The cross section of the carriageway is equal to that of the main Italian highways and it is composed by two lanes, each 3.75 m wide, and a 3 m wide emergency lane with a roadside barrier and a median barrier. The median is 2.60 m wide.

Nine different configurations of the crossover work zone were designed on the same 7 km long section of motorway and implemented in the driving simulator.

Particular attention has been placed on temporary signs and barriers, all built using a three dimensional software and introduced in the motorway scenario.

The experimentations were carried out during daylight conditions and using dry pavement conditions.

The type of work zone is a crossover in which the traffic flow northward is diverted to the opposite carriageway where two traffic streams travel in opposite directions, each on one lane (Fig. 1).

The speed is reduced from 130 to 60 km/h before the by-pass location by means of progressive speed limits and to 40 km/h in the by-pass.

The alignment implemented in the simulator is composed of the following sections:

- an initial 3500 m long section of standard motorway layout;
- a work zone section of 3380 m that includes the advance warning area (696 m), the transition area (372 m), the entrance by-pass (40 m), the activity area (2184 m), the exit by-pass (40 m) and the termination area (48 m).

The signs are consistent with the Italian technical rules for temporary signs (Ministero delle Infrastrutture e dei Trasporti, 2002).

The advance warning area contains six pairs of signs with one sign located on each side of the roadway. The user encounters at first the "road work" signs (Fig. 2, top left), then, the other traffic signs arranged at a distance of 120 m from one another. Specifically they consist of the 110 km/h speed limit, the 90 km/h speed limit, the "right lane closure" sign and the 60 km/h speed limit sign. The "right lane closure" sign is then repeated and represents the last sign encountered in the advance warning area.

Approximately 90 m after the "right lane closure" signs there is the transition area (Fig. 2, top right), which consists of two distinct sections:

- a 108 m long merging taper (realized with delineators and "keep left" signs) that closes the slow lane and requires drivers to move on the overtaking lane;
- a 250 m long section on the overtaking lane where the speed limit is reduced to 40 km/h.

The 40 km/h speed limit sign is placed about 100 m before the end of the transition area, followed by the "carriageway closure" sign placed 36 m before the entrance by-pass (Fig. 2, bottom left) where traffic is diverted to the opposite carriageway through a single-lane crossover.

In correspondence of the activity area the opposite traffic flows are concentrated on the southbound carriageway, with a single lane for each travel direction.

The standard channelizing devices used to separate the traffic flows consist of 30 cm tall flexible delineators placed at a distance of 12 m from each other.

Moving along this section the user encounters a "No Overtaking" sign placed about 85 m after the by-pass and then, at a distance of 120 m, the 80 km/h speed limit that applies to all the activity area. The speed limit is subsequently reduced prior to 60 km/h at 228 m distance before the exit by-pass and then to 40 km/h before the 40 m wide median opening that moves the traffic back to their carriageway (Fig. 2, bottom right).

The termination area includes the taper to direct the traffic back into the roadway after traversing the activity area. This area ends with the "End of road work" sign, placed 48 m after the exit by-pass.

The configuration described above has been considered as the reference configuration (configuration "0").

Eight alternative configurations have been analyzed (named configurations "0_VMS", "1", "2", "3", "4", "5", "6" and "7"), differing from the reference one for the characteristics listed in Tables 1 and 2.

Configurations "0", "0_VMS", "1", "2" and "3" have been designed and then analyzed within the ASAP project (Cocu et al., 2014). The measures implemented in these configurations, whose characteristics are listed in Table 1, have been focused on the homogenization of the speed by facilitating the crossover manoeuvre (wider median opening – 80 m instead of 40 m – or wider lanes – 5 m instead of 3.75 m – or both) or increasing the posted speed limits (80 km/h in the transition area instead of 60 km/h and 60 km/h in the entrance or exit by-passes instead of 40 km/h). An additional measure has

[1] The 5 m lane width is implemented starting from the beginning of the transition area till the end of the termination area (Fig. 1). The lane width within the advance warning area is still 3.75 m.

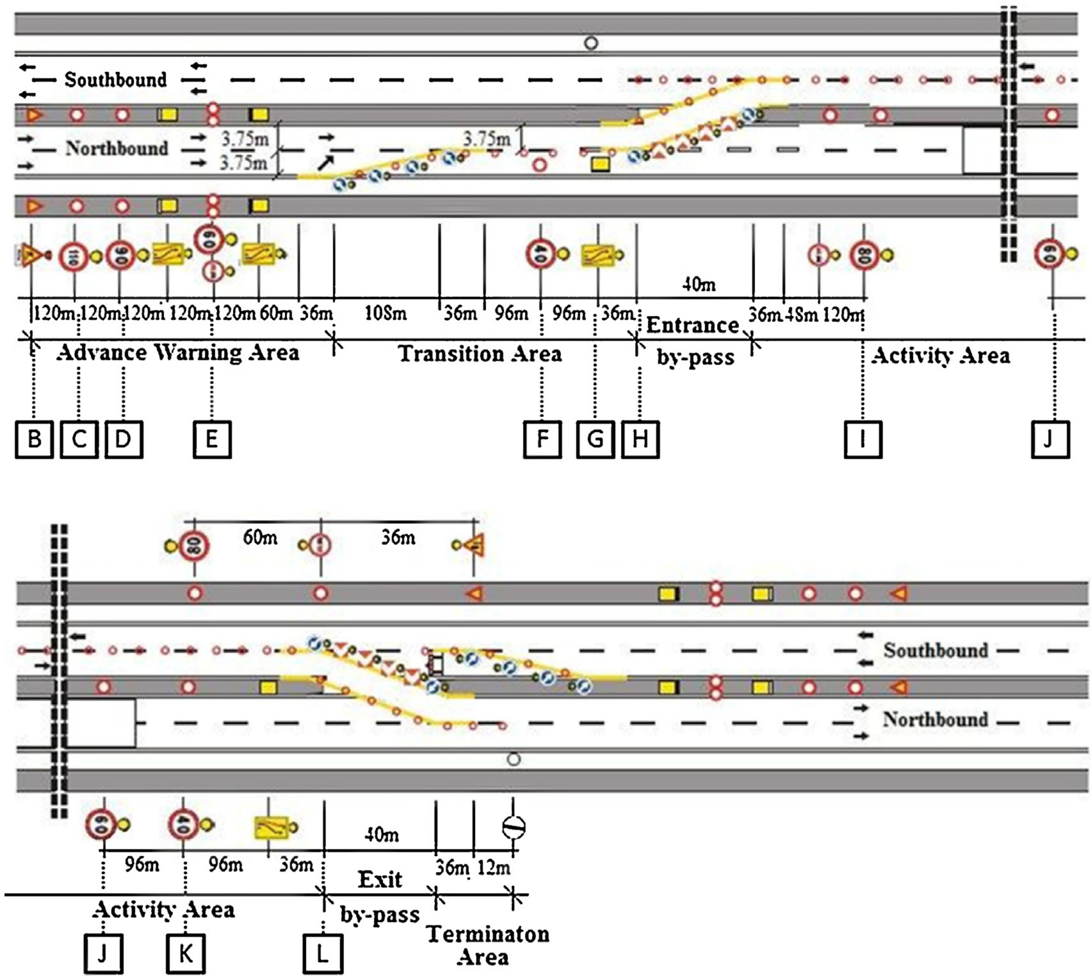

Fig. 1. The crossover layout.

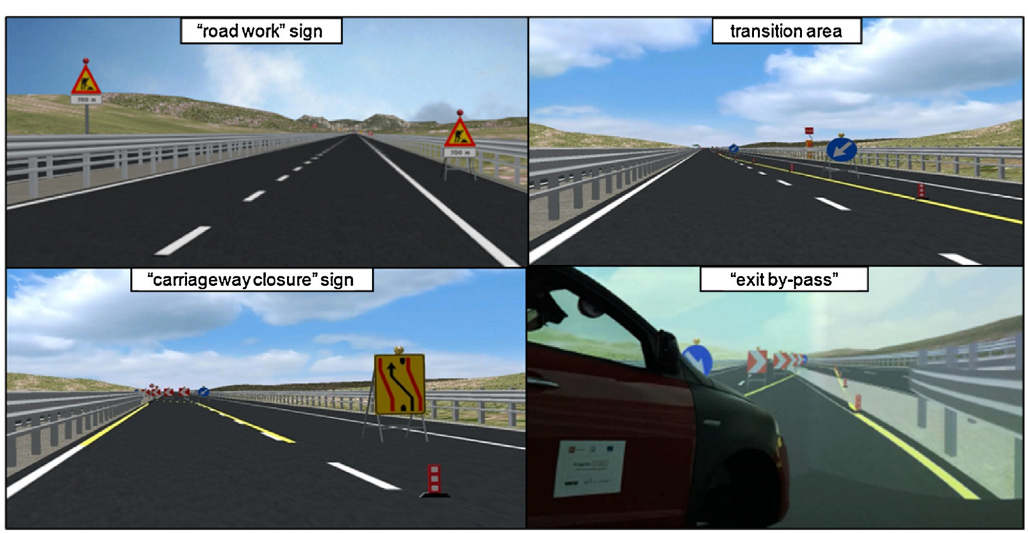

Fig. 2. Work zone areas – reference configuration (Configuration "0").

been considered in configuration "0_VMS", additive to the reference configuration, consisting in the installation of a VMS showing the message "Reduce the speed", located at the beginning of the Advance Warning area (Fig. 4, top left).

The configurations "4", "5", "6" and "7", whose characteristics are listed in Table 2, have been focused in obtaining the same result (homogenization of the driving speed) by means of traffic calming measures based on HF principles (PIARC, 2012). The speed chosen by the drivers is mostly an unconscious process, depending on the

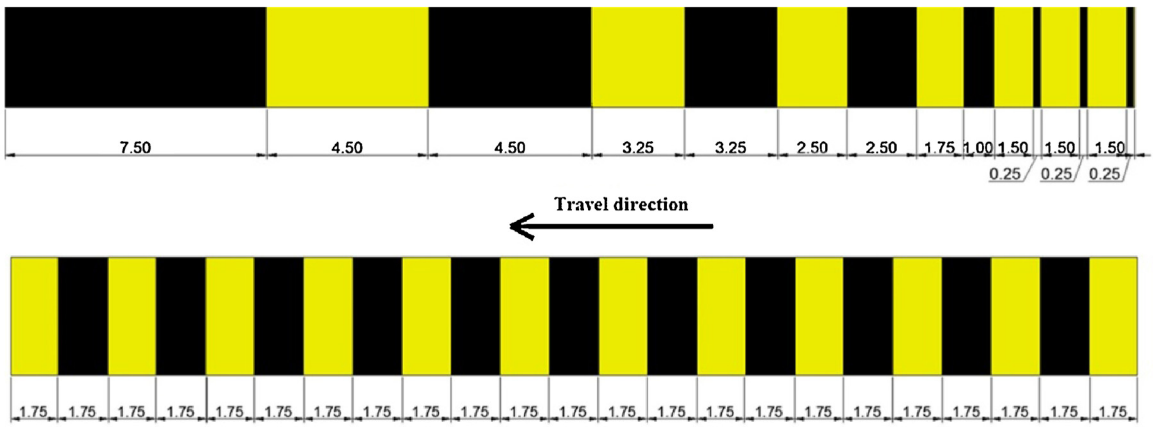

Fig. 3. Frame textures.

Table 1
characteristics of the alternative configurations (“0_VMS”, “1”, “2” and “3”).

Configuration	Differences with configuration “0”
0_VMS	• A VMS in place of the “road work” sign is installed on the right shoulder. The VMS sign reads “Riduci la velocità” (“Reduce the speed” in Italian)
1	• Wider median opening: 80 m instead of 40 m (both for the entrance and the exit by-pass); • A different sequence of speed limits in the advance warning area: 110–80 km/h, instead of the sequence 110–90–60 km/h (the 80 km/h limit in place of the 60 km/h limit and the speed limit sign of 90 km/h removed); • The speed limit of 40 km/h in the by-pass is increased to 60 km/h; • The speed limits of 60 km/h and 40 km/h within the activity area are increased respectively to 80 km/h and 60 km/h
2	• The lane width for the flow travelling through the work zone is increased from 3.75 m to 5 m (achieved through the lateral displacement of delineators and yellow lines with the original white lines left in place). The width of the median opening is 40 m[1]
3	• Wider median opening: 80 m instead of 40 m (both for the entrance and the exit by-pass); • A different sequence of speed limits in the advance warning area: 110–80 km/h, instead of the sequence 110–90–60 km/h (the 80 km/h limit in place of the 60 km/h limit and the speed limit sign of 90 km/h removed); • The speed limit of 40 km/h in the by-pass is increased to 60 km/h; • The speed limits of 60 km/h and 40 km/h within the activity area are increased respectively to 80 km/h and 60 km/h; • The lane width for the flow travelling through the work zone is increased from 3.75 m to 5 m (achieved through the lateral displacement of delineators and of the yellow lines with the original white lines left in place)

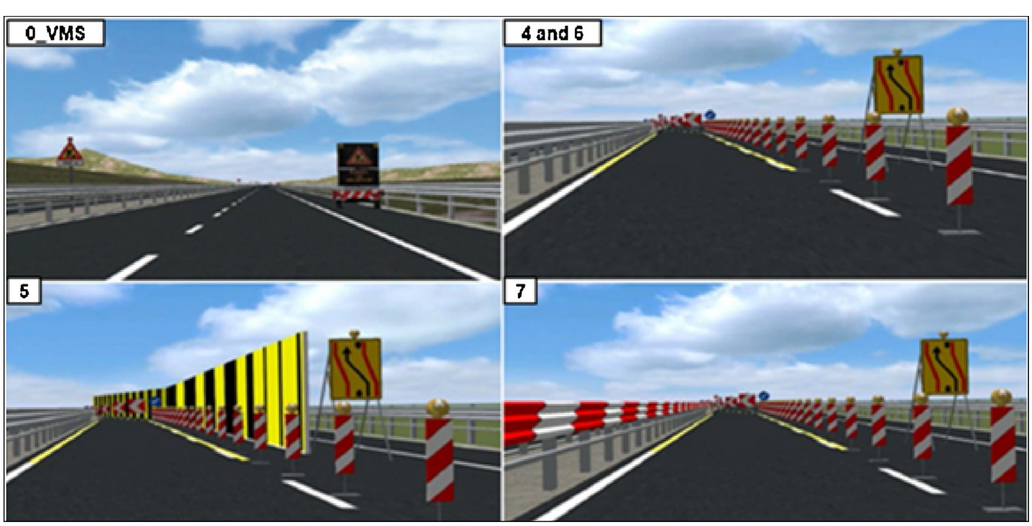

Fig. 4. Images of some work zone's configurations in the transition area.

interaction of human information processing with the optical density of the field of view (PIARC, 2008). The latter is a function of the visual information and can be defined as the number of objects that contrast with the background.

An optimal level of optical density, stimulating the driver without overloading him, and the reduction of the perceived spatial depth of the field of view lead unconsciously to slow down (PIARC, 2008). The amount of information to be processed influences the

Table 2
characteristics of the alternative configurations ("4", "5", "6", and "7").

Configuration	Differences with configuration "0"
4	• 1.10 m high vertical delineators, placed at a distance of 3 m from each other, replace the flexible delineators (0.30 m high) in the transition area; • Larger sized chevron alignment signs (used to provide additional guidance for the crossover chicane). Their dimensions decrease in the direction of the activity area: four chevron signs having dimensions 150 × 150 cm, 120 × 120 cm, 90 × 90 cm, 90 × 90 cm replace the 90 × 90 cm standard sized chevrons adopted in the reference configuration
5	• 1.10 m high vertical delineators, placed at a distance of 3 m from each other, replace the flexible delineators (0.30 m high) in the transition area • Larger sized chevron alignment signs (used to provide additional guidance for the crossover chicane). Their dimensions decrease in the direction of the activity area: four chevron signs having dimensions 150 × 150 cm, 120 × 120 cm, 90 × 90 cm, 90 × 90 cm replace the 90 × 90 cm standard sized chevrons adopted in the reference configuration • A 3 m tall visual frame placed in proximity of the entrance by-pass. The frame is made up of a series of black and yellow vertical stripes which increase in width in the travelling direction and consists of two different textures: the first one (Fig. 3, upper part), 36 m long, runs parallel to the travel direction from section G to section H, whereas the second one (Fig. 3, lower part), 40.25 m long, runs parallel to the chevron signs alignment starting from section H
6	• 1.10 m high vertical delineators, placed at a distance of 3 m from each other, replace the flexible delineators (0.30 m high) in the transition area • Vertical delineators are placed also within the advance warning area (starting from site B) and not only within the transition area. Delineators are located on the white line of the right shoulder • Larger sized chevron alignment signs (used to provide additional guidance for the crossover chicane). Their dimensions decrease in the direction of the activity area: four chevron signs having dimensions 150 × 150 cm, 120 × 120 cm, 90 × 90 cm, 90 × 90 cm replace the 90 × 90 cm standard sized chevrons adopted in the reference configuration • All speed limit signs are removed
7	• 1.10 m high vertical delineators, placed at a distance of 3 m from each other, replace the flexible delineators (0.30 m high) in the transition area • Vertical delineators are placed also within the advance warning area (starting from site B) and not only within the transition area. Delineators are located on the white line of the right shoulder • Larger sized chevron alignment signs (used to provide additional guidance for the crossover chicane). Their dimensions decrease in the direction of the activity area: four chevron signs having dimensions 150 × 150 cm, 120 × 120 cm, 90 × 90 cm, 90 × 90 cm replace the 90 × 90 cm standard sized chevrons adopted in the reference configuration • A visual pattern consisting of alternating red and white stripes (1 m wide) is painted on the median barrier starting from site B

quality of driving and therefore the driver's speed (Yerkes and Dodson, 1908).

Based on these principles the perceptual countermeasures included in configurations "4", "5", "6" and "7" consisted in taller vertical delineators (Fig. 4, top right), larger chevron signs, a visual frame with black and yellow vertical stripes (Fig. 4, bottom left) and a visual pattern consisting of red and white stripes painted on the median barrier (Fig. 4, bottom right).

3.4. Testing procedure

Upon arrival at the laboratory, each participant was briefed on the requirements of the experiment and was asked to read and sign an informed consent document.

The participants were given some basic information about the use of the simulator, warned about simulator sickness, and informed that they could stop the test at any time.

They were then asked to wear the safety belt and drive as they normally would, although they were not briefed about the research objectives.

Drivers then performed a 10-min training phase in order to familiarize with the vehicle and its control instruments such as the steering wheel, gearbox, accelerator and brakes. The training scenario was a motorway section with moderate traffic.

At the end of the training phase, the subject was asked to get down from the cabin and fill in a post-training questionnaire, containing a number of questions on the perceived discomfort. Then drivers took a 5-min break before starting the experimental session in order to re-establish psycho-physical conditions similar to those at the beginning of the test. Each participant encountered each of the nine configurations in varying random order to reduce bias within the data collection.

At the end of the experiment the subject was asked to fill a short post-experiment questionnaire to report the subjective evaluation of the effectiveness of the different work zone configurations, in terms of driving comfort and safety. These subjective data were used to estimate any potential inconsistencies between the objective data and the participant feelings.

3.5. Data collection and analysis

Although the simulator collected a great number of parameters, the study focused on the analysis of speed and deceleration based on the findings of the literature review that identified speeding and especially speed variance as the most critical factors for road safety in work zones.

The comparison between the speeds, collected at a sampling rate of 0.05 s, was carried out in the following sections (Fig. 5):

- at an upstream section located 500 m before the "work zone" sign (site A);
- at the "road work" sign (site B);
- at each speed limit sign (sites C–F, I–K);
- at the "carriageway closure" sign (site G);
- at the beginning section of the entrance by-pass (site H) and of the exit by-pass (site L).

For the comparative analysis between the different configurations, a bilateral Student t-test for unpaired data was carried out. In order to determine the statistical significance, a hypothesis was postulated and then the validity of that hypothesis was tested. In this study, the following two hypothesis were evaluated: (a) null hypothesis, the actual speeds in a specific site of two different work zone configurations belong to the same population; (b) alternative

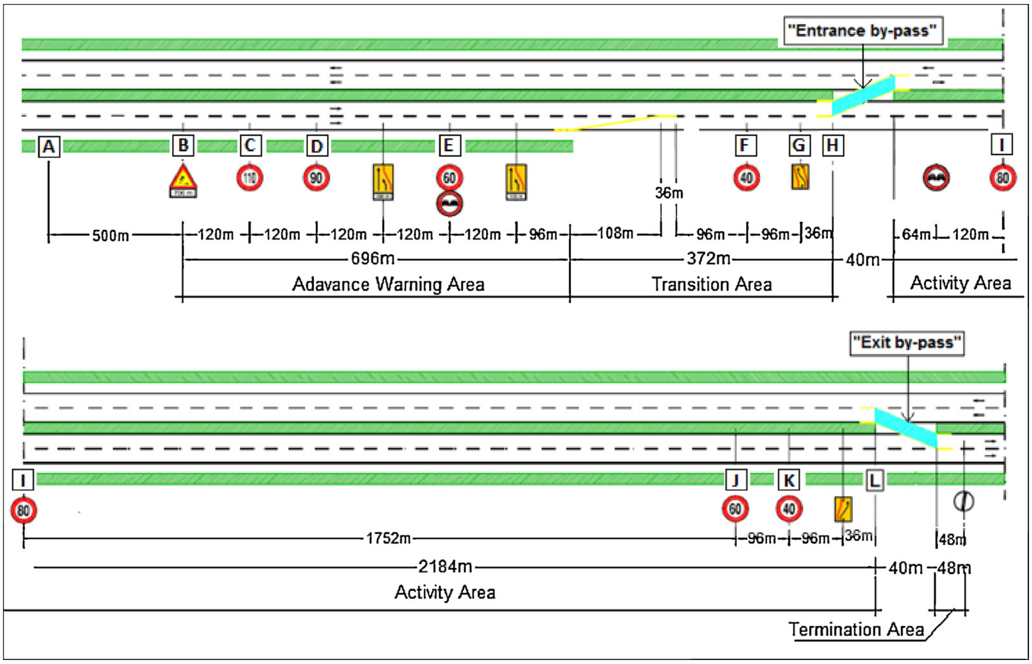

Fig. 5. Speed measurement sites (configuration "0").

hypothesis, the two samples do not belong to the same population. The test was performed at a level of significance of 5%.

4. Results and discussion

For the comparative analysis between the configurations, mean speeds, standard deviations, speed variances and mean decelerations were calculated. The values of mean speed, standard deviation and variance calculated for each measurement site are shown in Table 3 and 4.

The mean speed at each measurement site is computed as follows:

$$\mu_x = \frac{\sum_{i=1}^{n} V_{x,i}}{n} \tag{1}$$

where:

- x is the specific measurement site;
- n is the number of participants.

The standard deviation of μ_x is given by

$$Std.Dev(\mu_x) = [Variance(\mu_x)]^{0.5} = \sqrt{\frac{\sum_{i=1}^{n} (V_{x,i} - \mu_x)^2}{n}} \tag{2}$$

Considering the theory that the safest work zones are those with the smallest increase in the upstream-to-work-zone speed variance (Migletz et al., 1998), the changes in speed variance between an upstream section (site A) and a section inside of the work zone (site G), have also been used as a safety indicator in this study. The percentage change between these two sections is reported in Table 5.

The Student's *t*-test was performed in order to evaluate if the mean speeds recorded in each site of measurement of the alternative configurations were statistically different from those recorded within the reference configuration. The results in terms of p-values are shown in Table 6.

4.1. Speed behaviour in the reference configuration

The analysis of the speed driven in configuration "0" by the total sample of 42 participants showed a speed behaviour perfectly in line with that resulting from the ASAP project with a partial sample of 26 participants (Cocu et al., 2014).

In this configuration the average speed recorded upstream of the work zone (site A), when the normal speed limit is 130 km/h, is about 129 km/h (Fig. 6).

Then the drivers approach the warning area with a mean speed of 123 km/h at of the "road work" sign (site B) and start reducing progressively the speed.

The mean speeds at the "110 km/h speed limit" sign (site C) and in proximity of the "90 km/h speed limit" sign (site D) are respectively 117 km/h and 112 km/h and in site E the drivers adopt a mean speed higher than 100 km/h despite a speed limit of 60 km/h. At the 40 km/h speed limit the mean speed is still about 35 km/h higher than the temporary limit.

Two distinct phases of deceleration can be identified by analyzing the mean speed profile before the entrance by-pass: starting from the site B the users slow down with a mean deceleration of 0.35 m/s^2, then, in correspondence of a section within the merging taper about 250 m before the entrance by-pass, they reduce significantly the speed at a higher deceleration rate equal to about 0.81 m/s^2.

The percentage increase in speed variance between upstream (site A) and inside the work zone (site G) was about 48%.

According to the described speed profile, the actual speeds are much higher than the prescribed speed limits. Even in approach of the 40 m wide entrance by-pass (site H), where the flow is diverted to the opposite carriageway, the mean speed is about 50 km/h, still higher than the imposed speed limit of 40 km/h.

In the activity area the mean speed is always higher than the prescribed limit: after the end of the entrance by-pass, the users start accelerating, travelling with a speed of 83 km/h in correspondence of the "80 km/h speed limit" sign, and reach a maximum speed value

Table 3
Summary of results (from site A to site F).

Configuration		Measurement site					
		A	B	C	D	E	F
0	Mean Speed (km/h)	129.03	123.12	117.32	111.74	103.81	74.14
	Std. Dev. (km/h)	9.59	12.14	13.23	13.26	13.22	14.98
	Variance (km^2/h^2)	92.03	147.48	175.09	175.87	174.67	224.39
0_VMS	Mean Speed (km/h)	128.23	119.08	112.39	108.41	102.04	75.57
	Std. Dev. (km/h)	9.51	12.48	10.62	11.67	12.79	14.97
	Variance (km^2/h^2)	90.43	155.75	112.68	136.22	163.48	224.10
1	Mean Speed (km/h)	128.55	120.53	116.23	113.53	104.46	74.08
	Std. Dev. (km/h)	9.04	12.61	13.55	13.12	13.62	11.91
	Variance (km^2/h^2)	81.70	158.91	183.62	172.05	185.64	141.80
2	Mean Speed (km/h)	129.85	125.85	119.32	112.77	102.97	76.66
	Std. Dev. (km/h)	9.36	12.96	13.32	13.90	14.63	14.38
	Variance (km^2/h^2)	87.59	167.91	177.30	193.29	214.02	206.72
3	Mean Speed (km/h)	128.64	124.41	119.21	114.07	106.55	78.10
	Std. Dev. (km/h)	9.93	11.66	13.62	14.73	14.44	14.94
	Variance (km^2/h^2)	98.62	136.07	185.59	217.08	208.57	223.08
4	Mean Speed (km/h)	128.35	126.28	120.32	113.19	103.23	72.01
	Std. Dev. (km/h)	9.77	13.48	14.86	13.68	14.02	12.52
	Variance (km^2/h^2)	95.48	181.63	220.85	187.11	196.62	156.76
5	Mean Speed (km/h)	128.76	122.16	116.11	110.21	101.30	69.52
	Std. Dev. (km/h)	9.70	13.25	14.37	14.69	14.07	12.93
	Variance (km^2/h^2)	94.14	175.58	206.44	215.87	198.05	167.28
6	Mean Speed (km/h)	128.47	119.85	117.24	114.44	107.12	77.00
	Std. Dev. (km/h)	9.21	13.27	14.36	14.82	14.87	13.56
	Variance (km^2/h^2)	84.86	176.06	206.14	219.76	221.17	183.94
7	Mean Speed (km/h)	128.61	117.36	110.22	106.04	97.29	69.08
	Std. Dev. (km/h)	9.83	14.53	14.97	15.61	13.97	11.99
	Variance (km^2/h^2)	96.57	211.19	224.03	243.63	195.13	143.76

Table 4
Summary of results (from site G to site L).

Configuration		Measurement site					
		G	H	I	J	K	L
0	Mean Speed (km/h)	54.59	50.42	82.52	95.34	82.32	53.50
	Std. Dev. (km/h)	11.68	10.02	7.20	12.89	12.65	9.95
	Variance (km^2/h^2)	136.38	100.45	51.82	166.03	159.95	99.01
0_VMS	Mean Speed (km/h)	53.56	49.69	82.82	95.90	82.23	51.40
	Std. Dev. (km/h)	11.40	11.09	7.32	13.24	13.49	9.24
	Variance (km^2/h^2)	130.03	122.89	53.59	175.37	182.09	85.45
1	Mean Speed (km/h)	64.80	63.35	87.82	95.63	83.28	70.18
	Std. Dev. (km/h)	9.44	9.24	8.50	12.83	13.30	10.39
	Variance (km^2/h^2)	89.13	85.30	72.23	164.72	176.92	107.94
2	Mean Speed (km/h)	53.09	52.96	87.59	99.59	85.39	56.31
	Std. Dev. (km/h)	11.21	11.93	9.11	14.87	13.20	10.27
	Variance (km^2/h^2)	125.61	142.23	82.96	221.19	174.33	105.47
3	Mean Speed (km/h)	67.27	67.09	92.39	99.16	85.74	73.14
	Std. Dev. (km/h)	11.86	12.18	9.99	15.40	14.75	13.55
	Variance (km^2/h^2)	140.60	148.28	99.72	237.05	217.48	183.48
4	Mean Speed (km/h)	56.43	51.37	81.26	93.70	78.63	53.44
	Std. Dev. (km/h)	10.52	9.19	8.94	15.81	15.35	9.13
	Variance (km^2/h^2)	110.71	84.44	79.95	249.95	235.69	83.34
5	Mean Speed (km/h)	57.85	51.12	82.38	92.31	79.15	54.90
	Std. Dev. (km/h)	9.57	9.67	8.73	15.62	16.32	11.04
	Variance (km^2/h^2)	91.52	93.50	76.14	243.85	266.32	121.78
6	Mean Speed (km/h)	55.53	49.66	81.82	90.11	77.92	54.81
	Std. Dev. (km/h)	11.28	11.46	9.57	15.13	15.30	9.06
	Variance (km^2/h^2)	127.13	131.31	91.61	229.05	234.10	82.15
7	Mean Speed (km/h)	55.21	52.08	82.70	91.44	78.45	54.10
	Std. Dev. (km/h)	9.27	9.30	11.36	15.82	15.94	9.62
	Variance (km^2/h^2)	85.98	86.53	129.01	250.28	254.10	92.55

Table 5
Percentage change in speed variance between upstream to work zone areas.

Site		Configuration								
		0	0_VMS	1	2	3	4	5	6	7
A	Var (km^2/h^2)	92.03	90.43	81.70	87.59	98.62	95.48	94.14	84.86	96.57
G	Var (km^2/h^2)	136.38	130.03	89.13	125.61	140.60	110.71	91.52	127.13	85.98
G-A	Δ Var (%)	+48.20	+43.80	+9.09	+43.41	+42.57	+15.95	−2.79	+49.80	−10.97

Table 6
Student's *t*-test results.

Site	Configuration							
	0_VMS	1	2	3	4	5	6	7
A	0.713	0.822	0.702	0.860	0.756	0.904	0.794	0.852
B	0.152	0.359	0.333	0.817	0.276	0.739	0.260	*0.067*
C	*0.075*	0.718	0.504	0.748	0.347	0.698	0.978	**0.033**
D	0.244	0.549	0.735	0.458	0.633	0.630	0.398	*0.094*
E	0.550	0.829	0.789	0.377	0.854	0.213	0.301	**0.042**
F	0.675	0.985	0.446	0.241	0.712	0.264	0.261	0.206
G	0.694	**<0.001**	0.561	**<0.001**	0.468	0.183	0.721	0.800
H	0.763	**<0.001**	0.851	**<0.001**	0.665	0.754	0.762	0.460
I	0.854	**0.004**	**0.007**	**<0.001**	0.490	0.937	0.724	0.934
J	0.851	0.924	0.178	0.234	0.614	0.355	0.112	0.246
K	0.974	0.749	0.295	0.272	0.246	0.336	0.179	0.249
L	0.337	**<0.001**	0.224	**<0.001**	0.977	0.561	0.554	0.790

Note: boldface indicates statistically significant values with 5% level of significance; Italic indicates statistically significant values with 10% level of significance.

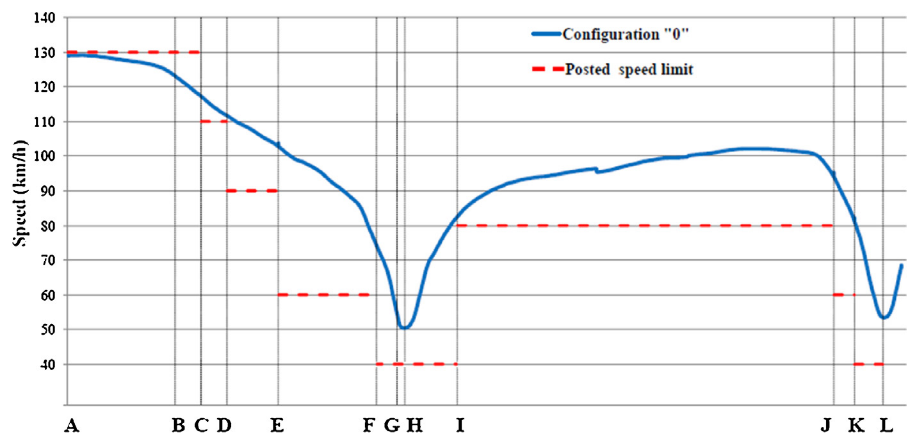

Fig. 6. Mean speed profile of configuration "0".

higher than 100 km/h. At a distance of about 250 m (similar to the driving behaviour in approaching the entrance by-pass) the drivers perceive the presence of the exit by-pass and reduce their speeds with a mean deceleration of about 1.14 m/s^2. The mean speed in the exit by-pass (site L) is 53.5 km/h.

These results show that the mean speeds within each work zone area are always higher than those prescribed by the temporary speed limits and decrease significantly only when the drivers recognize the presence of the by-passes perceiving them as a hazard.

4.2. The effect of the Variable Message Sign

In configuration "0_VMS" a Variable Message Sign (VMS) was installed in place of the "road work" static sign (site B), in order to investigate the effectiveness of this countermeasure on speed reductions.

The mean speed recorded at the upstream section (site A) is approximately the same for both configurations. This is likely due to the fact that drivers don't yet perceive the presence of the work zone at this distance.

In site B the mean speed measured in correspondence of the VMS (119 km/h) is about 4 km/h lower than that recorded at the "work zone" sign (123 km/h). This difference is maintained in the following section (site C) where the speed in configuration "0_VMS" is 112 km/h. Afterwards, the benefit of the VMS decreases and disappears at site E.

This result confirms the findings of previous research (La Torre et al., 2013) indicating that VMSs have a greater impact on driver speeds as compared to traditional static signs, even though the speed reductions are usually lower than 10 km/h. Also the driving simulator study conducted by Sommers and McAvoy (2013) found slight speed reductions (lower than 5 km/h) due to the implementation of a VMS at the beginning of a stationary work zone.

4.3. The impact of changes in speed limits

The configuration "1" was designed to verify the effect of the different sequence of speed limits in the advance warning and in the transition areas (110–80–60 km/h, in place of the reference sequence 110–90–60–40 km/h). The comparison between the mean speeds profiles of configuration "0" and configuration "1" are shown in Fig. 7.

Although the speed limits are consistently changed (+20 km/h) the mean speed profile does not change significantly. Within the advance warning, the transition and the activity areas, the mean speeds recorded in configuration "1" are approximately the same than those in configuration "0". The speed increases significantly only at the entrance and exit by-passes, where the mean speed recorded in configuration "1" is about 15 km/h higher than that of the reference configuration. However this difference is very likely due to the wider median opening (80 m instead of 40 m), rather than to the different speed limit sequence.

The mean speeds recorded along the activity area are much higher (up to 20 km/h) than the posted limits for both configurations. The field measurements used for the validation of the LaSIS driving simulator for work zone design, confirm this trend: the mean speed measured at one site within the activity area was 91.5 km/h, 11.5 km/h faster than the prescribed limit of 80 km/h.

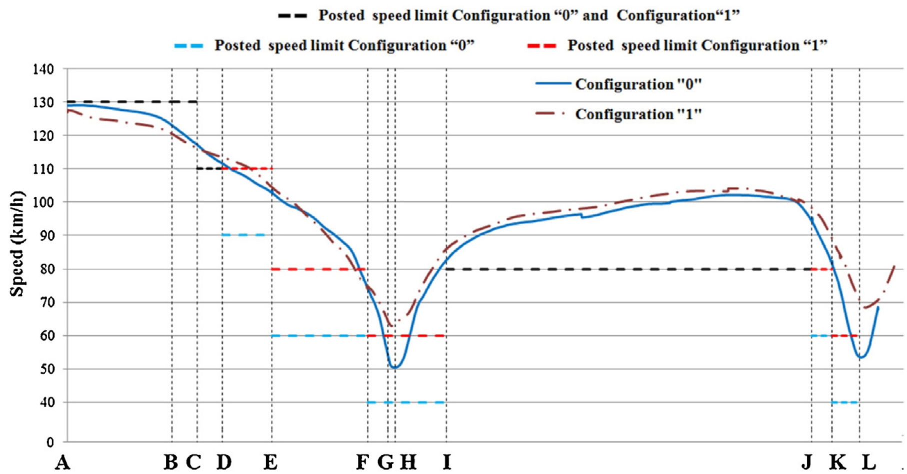

Fig. 7. Comparison between mean speed profiles (configurations "1" and "0").

These findings are consistent with those reported by Bella (2009b) that found no significant effects due to the change of work zone signs and speed limits and recorded driving speeds much higher than the temporary limits within all work zone areas.

Worker exposure to motorized traffic flow should be limited whenever possible. The portion of vehicles speeding through the activity area should be also reduced as drivers travel very close to the worker activities. Road agencies should therefore deploy specific law enforcement and speed management strategies near the activity area to encourage compliance with speed limits as drivers pass by the workforce.

A smoother variation of the actuated deceleration can be observed when approaching the transition area: instead of actuating the deceleration in two distinct phases, as in configuration "0", the deceleration gradually increases in three different phases from 0.25 m/s^2 to 0.42 m/s^2 and then to 0.51 m/s^2.

The reduced value of the final deceleration is very likely due not only to the higher speed limits but mainly to the widening of the median opening implemented in this configuration.

The analysis of the percentage change of speed variances from the section upstream (site A) to the section of the "carriageway closure" sign (site G) of configuration "1" shows a smaller increase in speed variance (+9.1%), compared to that measured in configuration "0" (+48.2%). Therefore, based on the literature experimental evidence that smaller changes in speed variance between upstream to inside work zone cause a lower potential for crashes, the sequence of speed limits (together with the 80 m opening width) implemented in configuration "1" seems to provide safer conditions for drivers even if no modification occurs in their speeding behaviour and a general increase of the mean speed values occurs.

The speed profile recorded in configuration "6", where all speed limits are removed and perceptual countermeasures implemented, is similar to that of configurations "0" and "1" (Fig. 8).

This evidence demonstrates that the speed actuated by drivers is mainly influenced by the field of view rather than by the posted speed limits. No changes in the speed profile occur by increasing the speed limits without changing the optical density of the field of view and still the same speed profile is attained when the posted speed limits are removed and the optical density of the field of view is increased.

In the latter condition a reduced deceleration occurs at the beginning of the manoeuvre (−0.25 m/s^2 in the advance warning area) and greater values occur afterward (−0.55 and −1.14 m/s^2) indicating a retarded reaction of the drivers when no explicit speed limit sign exists. This reflects also on the increase of the speed variance difference between upstream-to-work-zone (+49.8%).

4.4. The effect of a wider median opening

In order to verify the effect of increasing the median opening width in configuration "1" (80 m in place of 40 m), the mean values recorded in sites H and L were compared with those adopted in the reference configuration.

The comparison shows that the speed increases as the median opening increases. The mean speed at the entrance by-pass (site H) increases from 50.4 km/h of the reference configuration to 63.3 km/h of configuration "1", while the recorded mean speeds at the exit bypass (site L) are respectively 53.5 km/h and 70.2 km/h. The differences of the speeds within the by-passes are statistically significant according to the *t*-student test (Table 6).

Furthermore, the mean deceleration recorded between the site F ("40 km/h speed limit" sign) and the entrance by-pass is much lower when the drivers approach the 80 m opening width (−0.51 m/s^2) if compared to that recorded in approaching the 40 m by-pass (−0.81 m/s^2 or more). In addition, a lower value of the speed variance has been recorded in site H compared to that measured in the same section of reference configuration (Table 3).

According to these results it can be concluded that a larger width of the median opening allows the users to complete the manoeuvre safely even at higher speeds, avoiding sudden decelerations or abrupt manoeuvres.

4.5. The effect of the increase in lane width

In order to investigate the effect of the increased lane width (5 m instead of 3.75 m) the mean speeds along the transition and the activity areas of configuration "2" has been analyzed.

The mean speed profiles (Fig. 9) show no significant changes within the advance warning and the transition areas, while in the activity area the speed values with the 5 m wide lane are always higher than those recorded with a 3.75 m lane.

The analysis of the change in speed variances shows a similar value (+43.4%) than the one recorded for configuration "0" (+48.2%). According to this result, a wider lane width does not seem to provide safer conditions.

Furthermore, the mean speeds recorded within the entrance and exit by-passes of the configuration "2" are slightly higher than those recorded in the configuration "0". The lane width is therefore a fac-

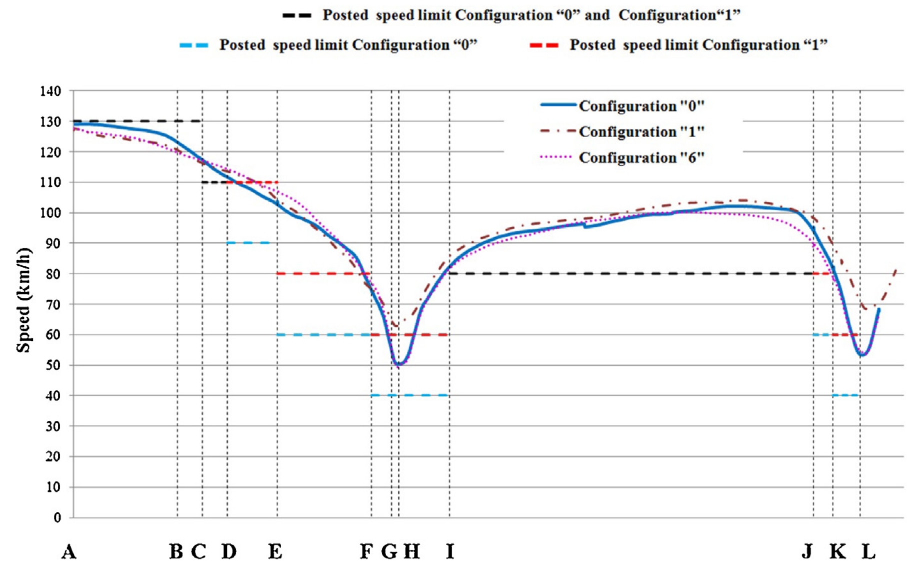

Fig. 8. Comparison between mean speed profiles (configurations “0”, “1” and “6”).

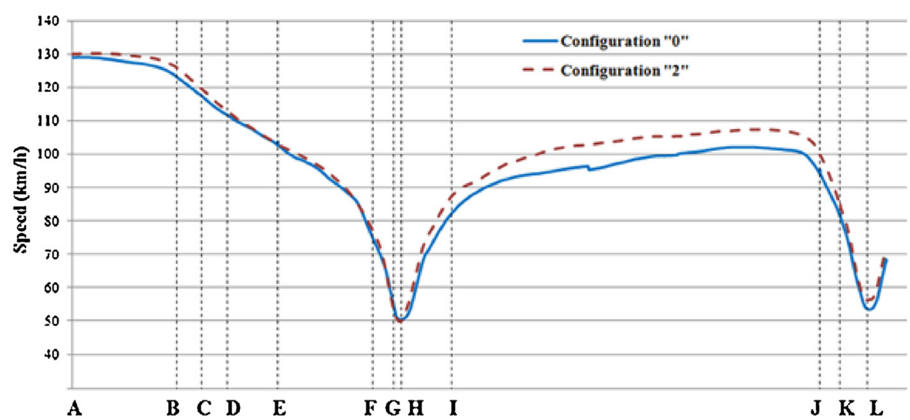

Fig. 9. Comparison between mean speeds profiles (configurations “2” and “0”).

tor that influences the speeds within the by-pass independently from its width.

4.6. The impact of perceptual treatments

The perceptual treatments, tested within configurations “4”, “5”, “6” and “7”, include the 1.10 m high vertical delineators with reduced spacing (3 m instead of 12 m), chevron alignment signs of greater dimensions in approaching the by-pass, a visual frame with a texture of black and yellow vertical stripes and a visual pattern consisting of alternating red and white stripes painted on the median barrier.

The analysis of speeds recorded in configuration “4” shows that the use of higher vertical delineators within the transition area, in place of the flexible delineators used in the reference configuration, does not seem to provide significant effects in reducing speeds. However a homogenization of the speeds seems to occur in configuration ‘4’: a smaller increase in the upstream-to-work-zone speed variance (+16.0%) has been recorded, compared to that measured in configuration “0” (+48.2%).

The mean speed profile of configuration “5” (Fig. 10) shows a relevant speed reduction within the transition area between sites E and F, where, in correspondence of the 40 km/h limit sign the mean speed is about 5 km/h lower than that recorded in the reference configuration.

The presence of the visual frame with black and yellow vertical stripes seems therefore to provide a strong visual impact to the driver. However this finding should be interpreted with caution as the visual frame is located about 500 m downstream of site E, and it is therefore unlikely that the speed reduction effect may be entirely due to the black and yellow texture.

A smoother variation of the actuated decelerations has been recorded in this configuration compared to those of the reference one. The mean decelerations gradually increase in three different steps from 0.37 m/s^2 to 0.50 m/s^2 and then to 0.81 m/s^2 in the proximity of the by-pass, while in configuration “0” they abruptly vary from 0.35 m/s^2 to 0.81 m/s^2 in two distinct phases.

The analysis of the speed variance in sites A and G shows a greater speed homogenization being the speed variance in G less than in A (−2.79%).

The speeds held by the drivers when crossing the by-pass do not show changes compared to the reference configuration. This result confirms that the speed within the by-pass is mostly influenced by its geometrical characteristics.

The visual pattern applied to the median barrier, coupled with taller and denser vertical delineators (configuration “7”), resulted in the largest speed reductions within the advance warning and the transition areas. A 6–7 km/h decrease in mean speed has been recorded in the segment between the site B and the site F (Fig. 11).

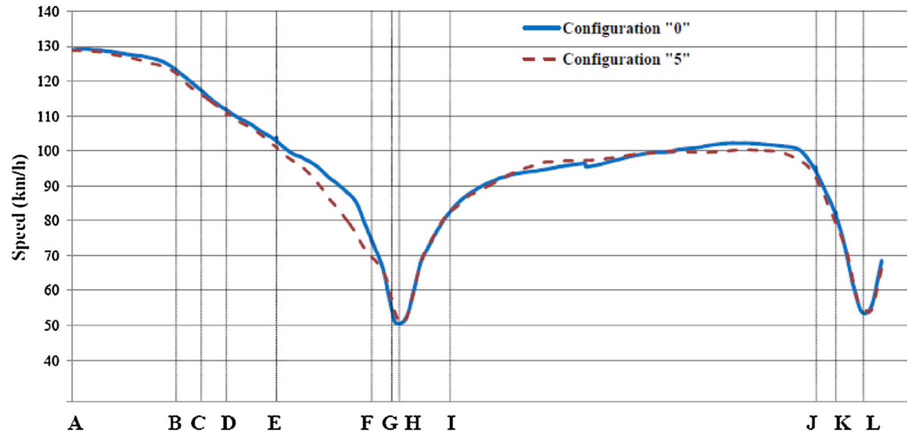

Fig. 10. Comparison between mean speeds profiles (configurations "5" and "0").

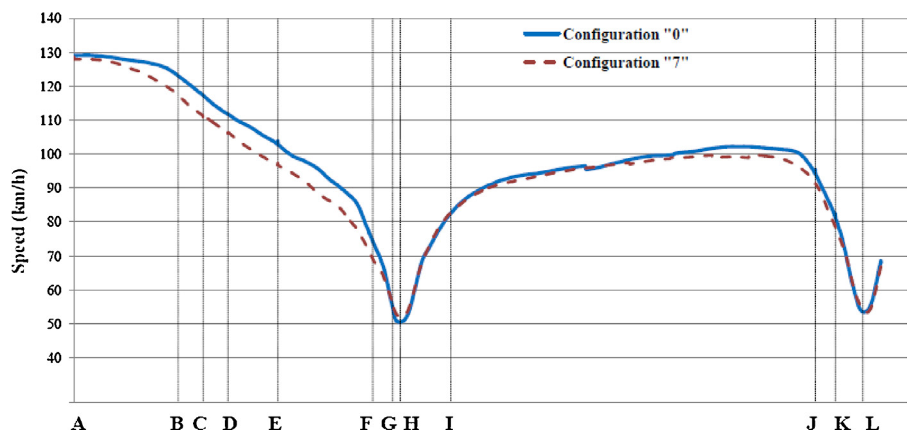

Fig. 11. Comparison between mean speeds profiles (configurations "7" and "0").

In this configuration a very slight variation of mean decelerations (0.34 m/s^2–0.56 m/s^2–0.66 m/s^2) and a reduction of the maximum deceleration value (−0.66 m/s^2 instead of −0.81 m/s^2) have been observed within the transition area.

Furthermore a greater homogenization of speeds is observed inside the work zone compared to the upstream area. Indeed a reduction percentage of speed variance from upstream to work zone equal to 11% was recorded in this configuration.

Although Allpress and Leland (2010) had already shown positive effects due to the implementation of traffic cones as perceptual measures, the findings of this study seems to confirm that perceptual countermeasures are likely to result in significant speed-reductions in roadwork sites and could have important implications for traffic safety.

4.7. Comparisons between scenarios

The comparison of the results in terms of speed variance, mean speed and deceleration values between the different configurations offers some interesting considerations.

The analysis of the percentage change of speed variances from the section upstream to the section inside the work zone (Fig. 12) showed a reduced increase in configurations "1" and "4" and a decrease in configurations "5" and "7" compared to that measured in the reference configuration. On the other hand, no significant differences in speed variance changes have been recorded in configurations "0_VMS", "2", "3" and "6".

These results seems to indicate that the safe conditions achievable by increasing the speed limits and widening the median opening (configuration "1") are also obtained by increasing the optical density of the field of view. The installation of taller and denser vertical delineators, the visual frame at the entrance by-pass and the visual pattern applied to the median have proven to be the most effective measures implementing such a principle.

Therefore, based on the theory that smaller increases in the upstream-to-work-zone speed variance cause a lower potential for crashes, the tested HF principle based configurations seem to provide the safest conditions for drivers. The results obtained are similar or even better than those obtained in the ASAP showcases with the use of speed camera signs (Cocu et al., 2014).

The mean speed values recorded at sites F and G in the different work zone configurations are summarized in Fig. 13.

The safe result in terms of speed variance obtained with configuration "1" is accompanied by a general speeding behaviour in approaching the entrance by-pass. When the median opening is increased to 80 m wide (configurations "1" and "3") the mean speed value at site F is similar to those obtained in configurations "0", "0_VMS" and "2", while the values at site G are higher than those of the other configurations as a consequence of the greater manoeuvre speed allowed by the wider median opening. On the other hand, in configurations "5" and "7" the reduction in speed variance is accompanied by a significant mean speed reduction, thus demonstrating a safer driving behaviour induced by the perceptual countermeasures.

The mean speed values within the by-pass are very similar for all configurations with the same median opening width (Fig. 14), regardless of the signing sequence or perceptual treatments implemented in the advance warning and transition areas. This confirms

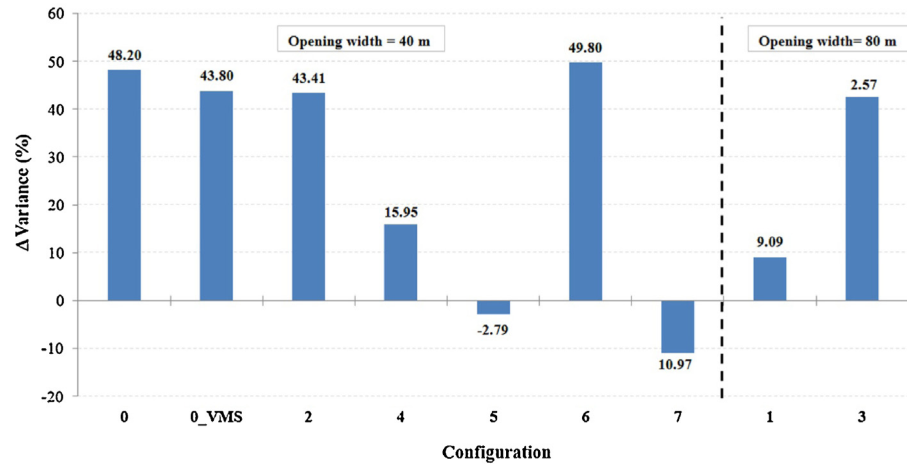

Fig. 12. Percentage changes in speed variance between upstream to work zone areas.

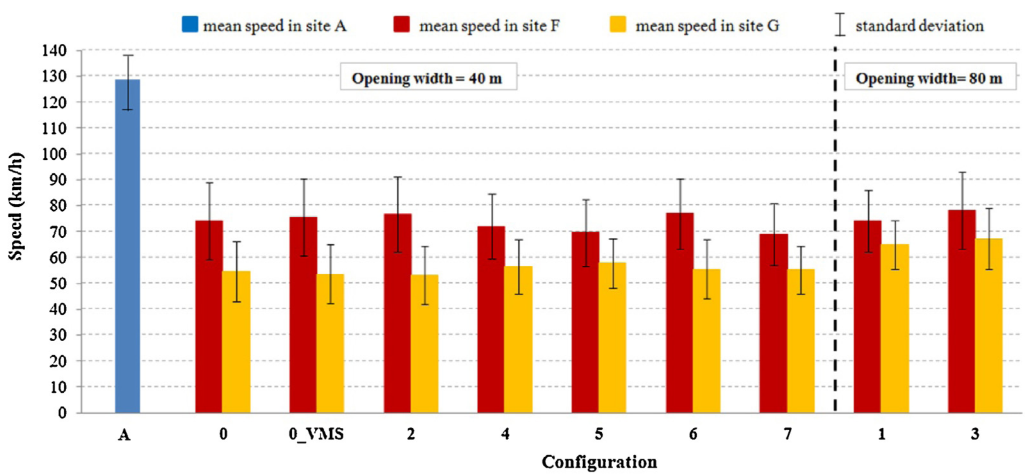

Fig. 13. Mean speeds upstream and in the proximity of the entrance by-pass.

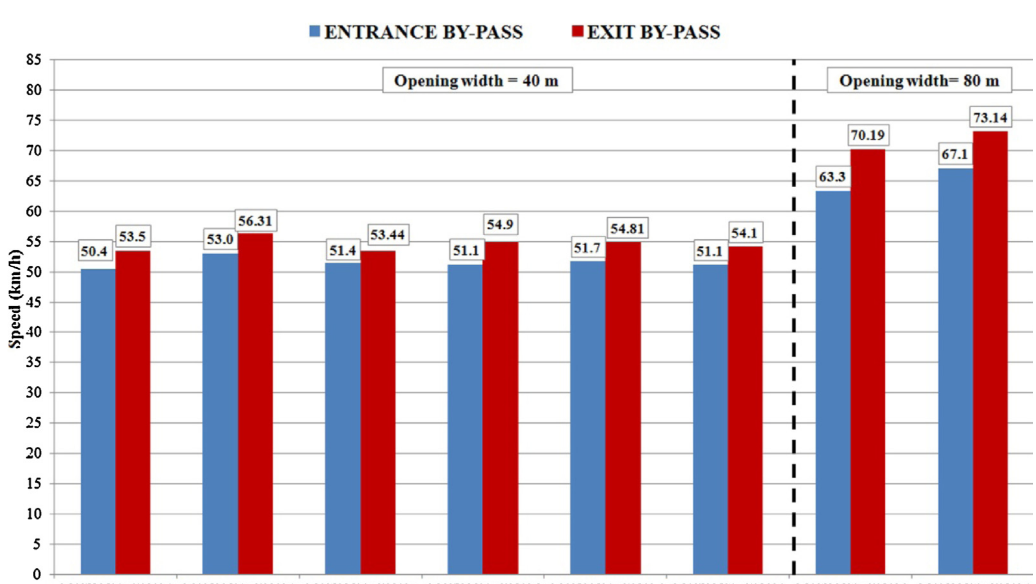

Fig. 14. Mean speeds within the by-passes for the different configurations.

that the speed within the by-pass is influenced by the geometrical characteristics of the median opening and not by the speeding behaviour upstream.

The maximum value of the recorded speed is attained in configuration “3” where, besides a wider median opening, a greater lane width is present. This result is likely due to the fact that the lane width influences the trajectory of the travelling vehicles, leading, in case of wider lanes, to greater freedom of manoeuvre for users in approaching the by-pass.

The analysis of mean decelerations in the advance warning and transition areas has shown that:

- the value of the initial deceleration within the advance warning area is mostly included in the range $-0.34/-0.38\,m/s^2$ (configurations “0”, “2”, “5”, “7”);
- the value of the final deceleration within the transition area is higher and ranges from -0.81 to $-0.85\,m/s^2$. Reduced values of the final decelerations ($-0.50/-0.66\,m/s^2$) are obtained with a wider median opening or in configuration “7”.

Two distinct behaviours can be identified:

- a manoeuvre in two distinct deceleration phases (configurations “0”, “0_VMS”, “2”);
- a manoeuvre in three deceleration phases (configurations “1”, “4”, “5”, “6”, “7”) in which the application of the higher final deceleration is more gradual, indicating a more careful behaviour in approaching the by-pass.

The results of the post-experiment questionnaire are consistent with the data recorded during the experimental activities. 40% of subjects stated that configuration 7 improved the driving comfort as compared to all other configurations, 29% of subjects stated they preferred the work one layout of configuration 1, 21% of participants preferred configuration 5, while the remaining 10% preferred configuration 4.

5. Conclusions

The results achieved in the driving simulation study clearly confirmed the literature findings indicating a general speeding behaviour within work zones. The drivers travel at higher speeds than those indicated by the temporary speed limits within all the work zone areas and within all configurations analyzed. The increase of temporary speed limits (configuration “1”) did not change the mean driving speed which was reduced only in the experiments performed including perceptual treatments in the field of view. This seems to indicate that the actuated speed is not influenced by the posted speed limit but mainly by the perceived characteristics of the field of view. A significant speed reduction (from 5 to 7 km/h) is obtained by introducing visual measures that increase the optical density of the field of view (configurations “5” and “7”), even though the driving speed is still higher than the temporary limits. The changes carried out exclusively on vertical delineators or on chevron sign dimensions (configuration “4”) seem not to be enough to achieve a significant speed reduction.

The mean speed decreases significantly only within the by-passes due to their geometrical characteristics. At the end of the deceleration phase, the by-pass is perceived as a critical section due to the particular manoeuvre to be actuated (chicane). The mean speeds are approximately the same for all configurations with the same opening width, regardless of the vertical sign configurations or perceptual measures adopted in approaching the work zone area. A wider median opening (80 m in place of 40m) led to an increase in mean speeds of about 13 km/h, whereas a wider travel lane (5 m in place of 3.75 m) led to a slight increase between 2 and 4 km/h.

The safer driving behaviour induced by a greater homogeneity of driving speeds, has been achieved:

- by adopting a wider median opening, together with higher speed limits;
- by adopting traffic calming measures acting on the optical density of the field of view.

The second measure showed a great effectiveness not only in reducing mean driving speeds in approaching the work zone area, but also in reducing the speed variances. The results confirmed the optical density of the field of view as an important parameter to induce an unconscious traffic calming effect.

A smoother variation of the actuated deceleration can be observed when approaching the transition area in configurations “1”, “4”, “5”, and “7” as compared to the reference configuration. The final mean deceleration recorded in approaching the by-pass was always much lower in those configurations with a wider median opening (80 m wide instead of 40 m). This shows that the crossover manoeuvre is mainly controlled by road-vehicle interactions rather than by road-user interactions.

The installation of a VMS seems to provide some effects on reducing speeds but localized within the advance warning area. The device tends to lose its effectiveness in the following areas.

Among the perceptual treatments analyzed, the visual pattern applied to the median barrier (coupled with taller and denser vertical delineators installed all along the advance warning and the transition areas) led to both the largest speed reductions and the greatest homogenization of speeds.

The results achieved with this research refer to a sample of 42 subjects aged between 24 and 50 years old. Further evaluation of the impact of other driver groups, such as younger and older drivers, could be appropriate in order to confirm the driving behaviour recorded in this study.

Furthermore, the sample included only 21% female participants and is therefore mainly representative of male drivers. As a matter of fact, the impact of gender on the driving behaviour has been the focus of some researches (Aronsson and Bang, 2006) but few references have been found concerning the impact of gender of the driving behaviour induced by perceptive measures. Darty et al. (2014), for instance, evaluated the user perception at a static driving simulator and reported that no significant correlation exists between gender and driving behaviour. Further research efforts should be necessary to assess whether gender can introduce bias in driving simulation studies and if differences in the driving performance of men and women induced by perceptive measures introduced in the drivers’ field of view have to be expected.

Based on the findings of the performed simulator study, on-field tests should be conducted in order to validate the results obtained. On-field tests are needed to investigate the effects in the real world of the considered countermeasures as well as to estimate their effects on the expected crash reduction.

Due to national regulations or road work site constraints, some parameters, such as speed limits, lanes width or geometry of the lane deviation when crossing the central reserve can’t be easily tested in real work zone sites. On the other hand, the “low cost” perceptual measures, such as the visual pattern on the median barrier coupled with higher vertical delineators, could be much more easily deployed in showcase scenarios so as to evaluate their real effectiveness.

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