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Full Length Article

Drivers' perception of highway work zone risks

Fadi Shahin [a,b,*], Wafa Elias [c], Tomer Toledo [b]

[a] Braude College of Engineering, 51 Snunit st., Karmiel 2161002, Israel
[b] Technion—Israel Institute of Technology, Haifa 32000, Israel
[c] Sami Shamoon College of Engineering, 84 Jabotinsky St., Ashdod 77245, Israel

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ABSTRACT

Highway work zones lead to an increase in crash risk. The goal of this research is to study drivers' risk perception to mitigate these risks. A questionnaire was used to study drivers' risk perception on typical highway work zone attributes (e.g., geometric changes, temporary traffic countermeasures, excessive speed). The results were compared with crash modification factors. A factor analysis was conducted to find the underlying latent variables behind these risk perceptions. Moreover, the connection between drivers' personal characteristics and their risk perception was studied using linear regression. Lastly, to study the association between drivers' risk perception and their driving speed, the questionnaire results were incorporated into a controlled experiment in a driving simulator that studied highway work zones effect on speed. A linear mixed-effects model was used to capture this association. The results reveal the most dangerous highway work zone attributes and the best mitigation ones perceived by drivers. Participants that drove more frequently through work zones drove at a higher speed in the driving simulator and the higher the perceived risk by the drivers the lower their speed. Male drivers have a lower perceived risk. These results can aid decision-makers in choosing safer highway work zone layout operations considering drivers' risk perception. Also, increasing the awareness of highway work zone risks will lead to safer work zones.

Introduction

Highway Work Zones (HWZs) are usually accompanied by an increase in the risk of traffic crashes [1–3]. Speeding is a major cause of road crashes in HWZs [4,5]. Studying HWZs effect on speed gives a partial grasp of the safety level. Another key component is understanding workers' and drivers' risk perception.

Workers and drivers are the ones experiencing HWZs hazards. They are familiar with the types of hazards and their common causes. They are also familiar with the safety measures for mitigating these hazards. Several studies aimed to mine this knowledge from workers and drivers through surveys and interviews. This knowledge can help improve work zone safety by understanding how road users perceive risk and what means will induce a safer environment. These studies' objective, participants, methods, and relevant findings are chronologically summarized as follows:

- Summala and Pihlman [6] examined 30,000 truck drivers' behavior regarding work zone safety. They sent a tape to the drivers explaining that workers get stressed and afraid when large vehicles pass them too fast and too close. They used video recorders to measure driving speeds in real work zones. The results show that truck drivers increased their lateral distance from workers when the traffic conditions allowed them to do it. However, they did not lower their speed after exposure to the tape, even when they could not increase lateral distance.
- Niskanen [7] studied which variables cause accidents at maintenance work zones. They used a questionnaire that was completed by 193 workers. The results show that many workers believe that risk-taking is part of their job and tend to overestimate traffic hazards.
- Benekohal and Shim [8,9] solicited semi-trailer truck drivers' input on work zone safety. They used a questionnaire that was completed by 930 drivers. The results show that 90 % agreed that driving through work zones is more dangerous than normal driving. One-third claimed that flaggers are hard to see, and half claimed that flaggers' directions are confusing sometimes or most of the time. One-fifth claimed that some signs should be added to the work zones.

* Corresponding author at: Braude College of Engineering, 51 Snunit st., Karmiel 2161002, Israel.
E-mail addresses: s9walaby@technion.ac.il, FadiS@braude.ac.il (F. Shahin).

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Most “bad driving situations” and accidents happen at the Advanced Warning Area (AWA) and transition areas. 50 % admitted to exceeding work zone speed limits. 70–85 % considered the traffic control devices helpful. Also, 85 % felt uncomfortable when there is a lack of shoulders and narrow lanes.

- Jamson et al. [10] developed safety indices for variables affecting traffic safety. They used a Delphi stated preference experiment. The participants were 150 traffic safety and driver behavior experts. The results show that driving at speeds over 50 % above the speed limit and a minimum headway of 0.5 s or less are extremely dangerous. Also, excellent driver awareness improves safety substantially.
- Debnath et al. [11] studied worker perceptions of common incidents in work zones. They interviewed 66 workers. The results show that the most common incidents are vehicles driving into work areas, vehicles hitting traffic controllers, rear-end crashes at roadwork approaches, and work vehicles and machinery reversing incidents. The incidents were attributed to drivers’ errors, such as speed limit violations, distracted driving, and ignoring signage and traffic controllers’ instructions.
- Debnath et al. [12] studied common hazards and their mitigating measures at work zones, they interviewed 66 highway workers. The most common hazards that they reported were excessive vehicle speeds, working in wet weather, and driver’s attitude toward workers. The safety measures reported to be most effective are active police enforcement and improving drivers’ awareness of work zones.

HWZ risk perception is affected by drivers’ personal characteristics. Understanding their effect can aid decision makers in choosing safer plans and increase drivers’ awareness. The following studies aimed to study the effect of personal characteristics on risk perception:

- Tronsmoen [13] studied self-assessment of driving ability. They used a questionnaire that was completed by 1419 drivers that were between 18 and 20 years old. The results show that male drivers and more experienced drivers had a higher self-assessment of driving ability.
- Martinussen et al. [14] studied the self-assessment of young male drivers of their own driving skill. A driving simulator was used with 31 participants. The results show inconsistency between self-assessment and driving performance. Also, self-assessments of hazard prediction and detection skills were particularly inaccurate.
- Steinbakk et al. [15] studied the effects of roadwork characteristics and drivers’ individual differences on speed preferences in a rural work zone. 845 drivers stated their preferred speeds at given pictures of work zones. The results show that male drivers have higher positive assessment of their driving skills. They also showed that higher positive assessment of driving skills is associated with higher preferred speed.

The literature review on road workers’ and drivers’ risk perception showed that the most common incidents at work zones are vehicles driving into work areas, vehicles hitting traffic controllers, rear-end crashes at roadwork approaches, and work vehicles and machinery reversing incidents. A considerable percentage of truck drivers showed some concern regarding several Temporary Traffic Control (TTC) effectiveness. Many factors were perceived to be hazardous by workers. The prominent ones are excessive vehicle speed, small headways, working in wet weather, and driver’s attitude. The safety measures perceived to be most effective by workers are active police enforcement and improving drivers’ awareness of work zones. The literature review on the personal characteristics effect on risk perception showed that male drivers and more experienced drivers had a higher self-assessment of driving ability; and higher positive assessment of driving skills is associated with higher preferred speed.

The following knowledge gaps were found: (1) Research is needed to identify which factors drivers perceive as hazardous and which safety measures are perceived as effective measures in mitigating risks. (2) No study was found that studied the association between drivers’ risk perception and their performance in a driving simulator through work zones. (3) No study was found that compared drivers’ risk perception with Crash Modification Factors (CMFs) which gives an indication of how countermeasures affect crash rates.

To address these gaps a questionnaire on drivers’ risk perception of typical HWZ attributes was built. The questionnaire is based on the literature’s findings about the HWZ risks and their mitigating measures ([6]; Benekohal and Shim, [8–12]). The results were compared with the available CMFs. Then a factor analysis was conducted to find the latent variables behind these attributes. Afterwards, in efforts to find how these latent variables are affected by personal characteristics a linear regression was conducted that examined the effect of gender, age, and years of driving experience on these latent variables. The findings are compared with the relevant studies [13–15]. Finally, to examine if these latent variables affect driving behavior, they were integrated into a driving simulator study (conducted by Shahin et al. [16]) and their effect on driving speed was examined.

Data

The data for this research was collected using a questionnaire and a driving simulator experiment. Section 2.1 presents the questionnaire designed for this study, its purpose, and the hypothesis made on the expected answers. The questionnaire results were incorporated into a driving simulator experiment to study the association between drivers’ risk perception and their driving speed. Section 2.2 presents the driving simulator experiment. This experiment investigated the effects of TTC countermeasures on HWZ safety and its results were used to examine the association between the drivers’ risk perception (based on their questionnaire’ answers) and their driving speed in the driving simulator. The detailed procedure and the effects of TTC countermeasures on HWZ safety are presented in Shahin et al. [16]. Section 2.3 presents the descriptive statistics of the participants that completed the questionnaire and the driving simulator experiments.

Questionnaire

A questionnaire to study drivers’ perception of HWZ dangers was devised. It contained questions about the participants’ personal characteristics that included gender, age, and years of driving experience.

Table 1
Drivers’ risk perception questionnaire.

	Question
1	In the last three months, on how many days on average did you drive a car during daytime hours on intercity roads?
2	In the last three months, on how many days on average did you drive a car during nighttime hours (night) on intercity roads?
3	In the last three months, on how many days on average did you drive a car during daytime hours on intercity roads that had changes due to a work zone area?
4	In the last three months, on how many days on average did you drive a car during nighttime hours (night) on intercity roads that had changes due to a work zone area?
5	In your opinion, how does the risk of road accident change when traveling on an intercity road where there are changes due to a work zone area compared to the situation where there are no work zone area during daytime hours?
6	In your opinion, how does the risk of road accident change when traveling on an intercity road where there are changes due to a work zone area compared to the situation where there are no work zone area during nighttime hours (night)?
7	In general, how do you change your travel speed when passing on intercity roads that have changes due to a work zone area during daytime hours?
8	In general, how do you change your travel speed when passing on intercity roads that have changes due to a work zone area during nighttime hours (night)?
9	Indicate for each of the following HWZ attributes to what extent, in your opinion, each attribute affects the level of risk of involvement in a road accident in the work zone area.

Then the participants were presented with nine questions that each collected an aspect of the participants' HWZ risk perception (Table 1).

The purpose of the questions (Table 1) along with the hypotheses made on the expected answers based on the literature review [13–15] are as follows:

Questions 1–4: Document how often the participants drove in the three months prior to participating in the driving simulator experiment. The questions were for driving during daytime/nighttime hours and through work/normal road operations. It is hypothesized that participants who drove more frequently would drive faster in the simulator. The participants were presented with five options as follows: did not drive at all, less than once a month, more than once a month but less than once a week, 1–3 days a week, and 4–7 days a week.

Questions 5–6: Solicit drivers' perceptions of HWZs effect on safety during daytime/nighttime hours. It was hypothesized that these perceptions affect how drivers behave within a HWZ compared to their behavior in normal road operations. The participants were presented with five options as follows: the risk increases greatly, the risk increases slightly, there is no change in risk, the risk decreases slightly, and the risk decreases greatly.

Questions 7–8: Document how much drivers change their speed when driving through HWZs during daytime/nighttime hours. The participants were presented with five options as follows: increase the speed by more than 20 km/hour, increase the speed by more than 10 km/hour, does not change speed, decrease the speed by more than 10 km/hour, and decrease the speed by more than 20 km/hour.

Question 9: Solicit drivers' perception of danger on 19 different HWZ attributes that included TTC, geometric changes, traffic conditions, and driving behavior attributes. They were based on the literature review (e.g., [8,12,11]) and few more attributes that are common to HWZs (e.g., scraped roads and road step). This part reveals which HWZ attributes are mostly perceived as increasing risks and which HWZ attributes are perceived as lowering risks. The participants were presented with five options as follows: the risk increases greatly, the risk increases slightly, there is no change in risk, the risk decreases slightly, and the risk decreases greatly. Factor analysis was conducted to find the latent variables of the 19 HWZ attributes. A linear regression to find the connection between drivers' personal characteristics and their risk perception was conducted. The results were combined with the LMEM to capture the association between the participants' questionnaire answers and their speeds in the driving simulator experiment.

Driving simulator experiment design

A STISIM Drive [17] simulator, located at the Technion – Israel Institute of Technology, was used in the study. STISIM Drive is supported for use as a valid measure for research [18]. The participants drove through a two-lane two-way inter-urban road. Each participant drove through eight scenarios. Each scenario contained a HWZs and the Advanced Warning Areas (AWAs) that precedes it. To reduce participants' fatigue and boredom, the scenarios were arranged in four simulator runs (containing two scenarios each) with a short break between them. Each run included driving 6 km, which in addition to the two scenarios included a final section without any work (noWZ), as shown in Fig. 1 [16]. The AWA and noWZ sections were 1-km long each. Road works were executed on the right shoulder causing lane narrowing. Lane widths in the AWAs and noWZ sections were 3.60 m. Depending on the experimental scenario, they were reduced to either 3.30, 3.00, or 2.70 m in the HWZ. There were no other differences in the road geometry between the AWA, HWZ and noWZ sections. Left and right shoulders were 1.8 m each. The posted speed limit was 90 km/h. It was reduced to 70 km/h in the HWZ. Daytime conditions were applied in all runs. Fig. 1 presents the studied TTC variables in Shahin et al. [16] that include Variable Message Signs (VMSs), Dynamic Speed Displays (DSDs), using rumble strips at the HWZ entry, and using rumble stripes in the HWZ at intervals of 300 m. After initial registration and consent form signing, participants were briefly introduced to the driving simulator and were given a 3 km trial drive to familiarize themselves with it. They were instructed to drive as they would normally do in the real world. After the experiment ended the participants filled out the questionnaire. Participation was voluntary.

Participants

90 valid participants participated in the simulator experiment and filled the questionnaire, 60 males and 30 females. They were students and staff members recruited on the Technion campus using billboards and announcements in social networks. None of the participants exhibited signs of driving sickness. Table 2 presents the descriptive

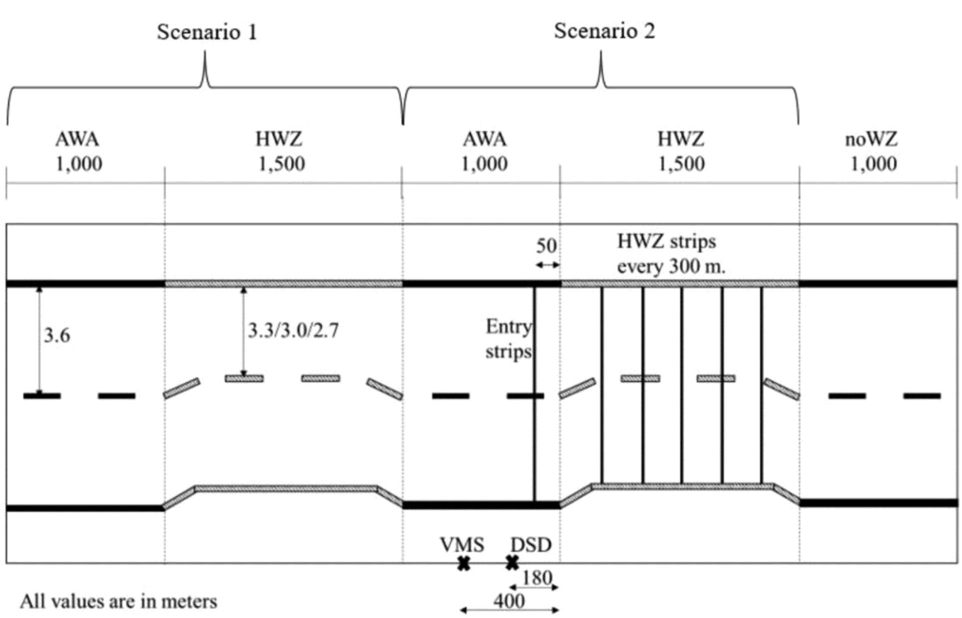

Fig. 1. Road layout for a diving simulator run (Source: [16]).

Table 2
Descriptive statistics of participants.

	Age	Driving experience
Mean	23.66	5.89
Median	23	5
Standard Deviation	2.62	2.47
Minimum	20	2
Maximum	30	12

statistics of participants age and years of driving experience.

Methods

Several methods were used to study drivers' risk perception. These included factor analysis, linear regression, and Linear Mixed-Effects Model (LMEM). The factor analysis was conducted to find the latent variables for the tested HWZ attributes (Question 9 in the questionnaire). The latent variables gave a better understanding of how drivers perceived the studied HWZ attributes. They were also used for finding the association between drivers' risk perception and their speed at the driving simulator experiment. In selecting the number of factors, the exclusion criteria were factor loading lower than 0.4. Also, any attribute that led to an alpha Cronbach lower than 0.7 was excluded (poor internal consistency). The factor analysis was conducted using R.

Linear regression was used to find the connection between the participants' personal characteristics and their risk perception. Factors with P-value higher than 5 % were excluded from the model. This was conducted on Excel.

An LMEM [19] was used to capture the effect of participants' personal and values for the latent variables found in the factor analysis, as well the countermeasures used in the experiments on their speed selection in the simulator experiment. This model structure captures both fixed and potentially correlated random effects:

$$\ln(y_{ij}) = \beta_0 + \beta_1 X_{ij1} + \ldots + \beta_m X_{ijm} + \eta_{i0} + \eta_{i1} X_{ij1} + \ldots + \eta_{im} X_{ijm} + \epsilon_{ij} \tag{1}$$

$$\eta_i \sim N(0, \Omega); \epsilon_{ij} \sim N(0, \sigma^2)$$

Where, the indices *i, j* and *m* signify participants, observations (the 20 measurement points of each participant) and factors. y_{ij} is the dependent variable value. X_{ijm} is the value of factor for that observation. $\beta_0 \ldots \beta_m$ are the fixed effect parameters. η_{im} are normally distributed subject random effects. Ω is their $(m+1)x(m+1)$ variance-covariance matrix. ϵ_{ij} is a normally distributed error term with variance σ^2. η_i *and* ϵ_{ij} are independent of each other and identically distributed among the subjects.

Speed was calculated separately for each AWA, HWZ and noWZ section (Fig. 1), resulting in 20 data points (average speed) for each participant (each participant took 4 runs and each run contained two AWA and HWZ sections and one noHWZ section). These average speeds were calculated from instantaneous speed measurements taken every 0.1 s resolution at the driving simulator.

Results

Drivers risk perception

Questions 1–4 in the questionnaire (Table 1) shows that most participants drove through normal road operations 1–3 days a week, and through HWZs less than once a week but more than once a month (Fig. 2). Questions 5–6 show that most participants perceive driving through HWZs as more dangerous. At daytime, most participants said that HWZs slightly increase risk. At nighttime, most participants said that HWZs greatly increase risk (Fig. 3). Questions 7–8 show that most participants claimed that they reduce their speed by more than 10 km/

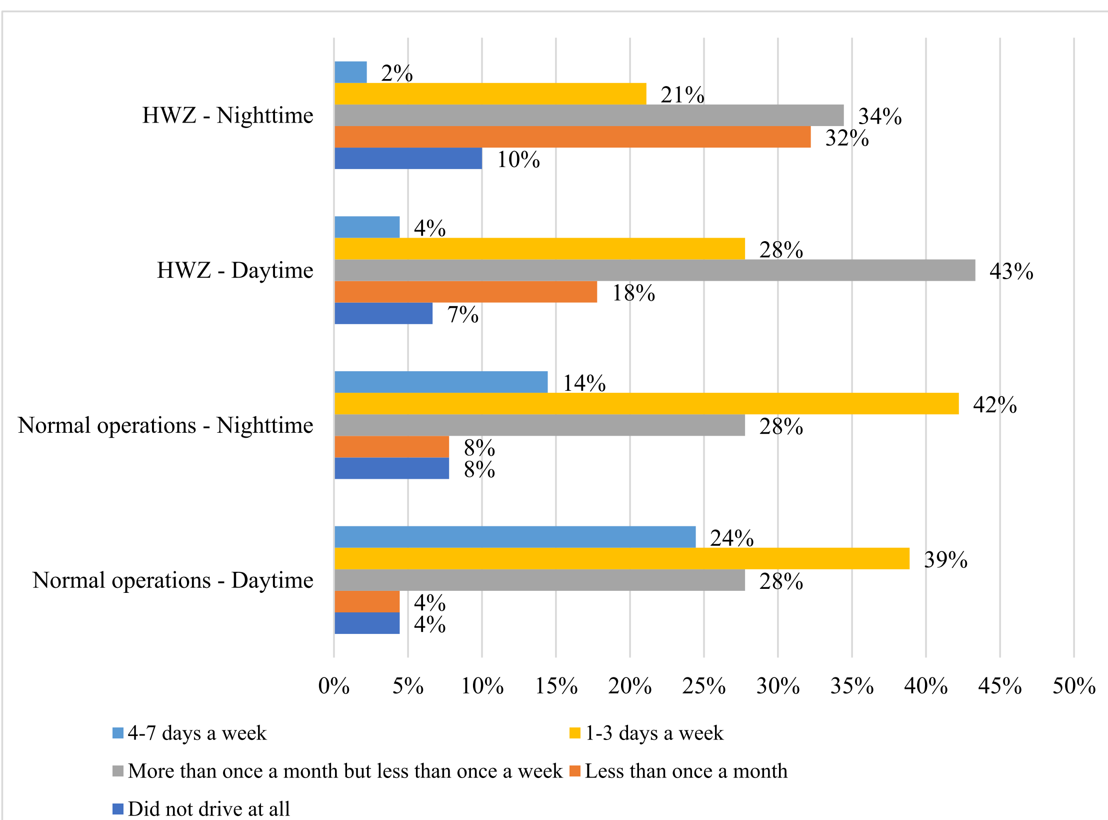

Fig. 2. Driving experience in the three months before the experiment.

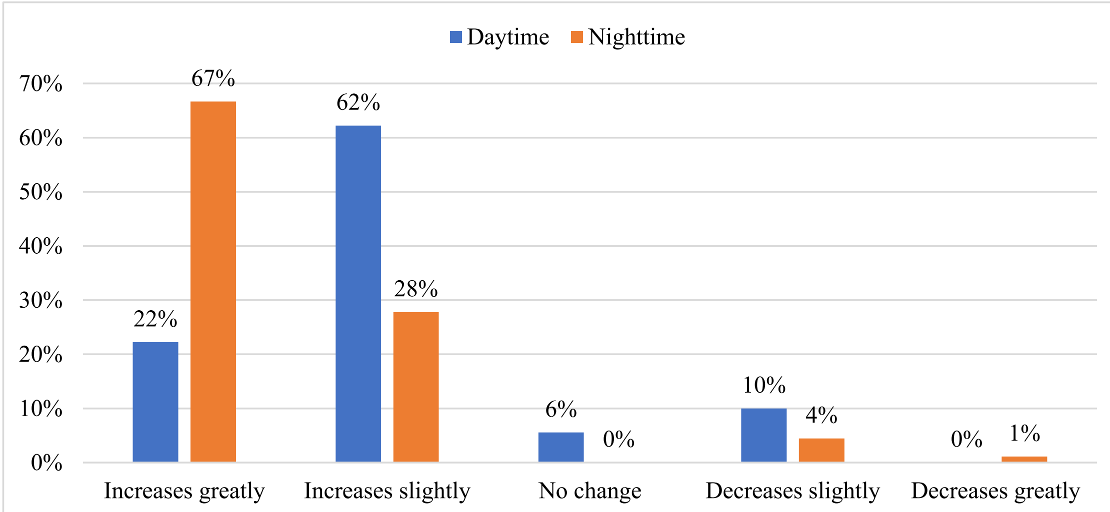

Fig. 3. Risk perception of HWZs compared to normal operations.

hr when traveling through HWZs at daytime and by more than 20 km/hr at night (Fig. 4).

The responses on the risk perceptions of the 19 HWZ attributes (Question 9 were on a 5-point Likert scale (1 is "the risk increases greatly", 5 is "the risk decreases greatly"). Fig. 5 presents the average questionnaire score of all participants for each of the 19 HWZ attributes. Smaller values suggest greater risk perceptions. Factors that had an average greater than 3 indicate that most participants agree that it reduces risk and any values lower than 3 indicate an increase in risk. The results show that excessive speeds, angry/frustrated drivers, and workers crossing the road are perceived as the most dangerous factors. DSD, VMS, flaggers, orange road signs, rumble strips, and police were perceived to decrease risk.

Among the 19 HWZ attributes, Crash Modification Factors (CMFs) are available in the literature for seven attributes ([20]; CMF, [21]).

Table 3 presents these values and the average risk perception values of the 5-point Likert scale response in the questionnaire (Fig. 5). A CMF lower than one indicates a crash reduction and an average risk perception greater than three indicates a perceived risk reduction of the attribute.

Table 3 shows a match between drivers' risk perception and objective CMFs from the literature. Attributes with a CMF lower than one had an average risk perception value greater than three and attributes with a CMF greater than one had an average value lower than three. For example, police presence has a CMF of 0.56 (leading to a 44 % reduction in crashes), and an average risk perception value of 3.8 which means that it is perceived as decreasing risk. Another example is driving with no shoulders that has a CMF of 1.21 (leading to a 21 % increase in crashes), and an average of 1.79 which means that it is perceived as increasing risk. Moreover, the higher the average of the attributes with an average value greater than three the lower their CMF.

Latent variables

Factor analysis was used to formulate underlying latent variable that affect perceptions of the 19 HWZ attributes and to study their association with the speed at the driving simulator experiment. The results of the factor analysis are presented in Table 4. Several HWZ attributes variables were excluded from the final model after a preliminary analysis of the data since they were poorly explained by the factor analysis (a factor loading lower than 0.4). Rumble strips had a factor loading of 0.4, therefore it was considered as one of the attributes in the physical disturbance latent variable. However, it was excluded after yielding an alpha Cronbach of 0.66. The optimal number of factor groups was found

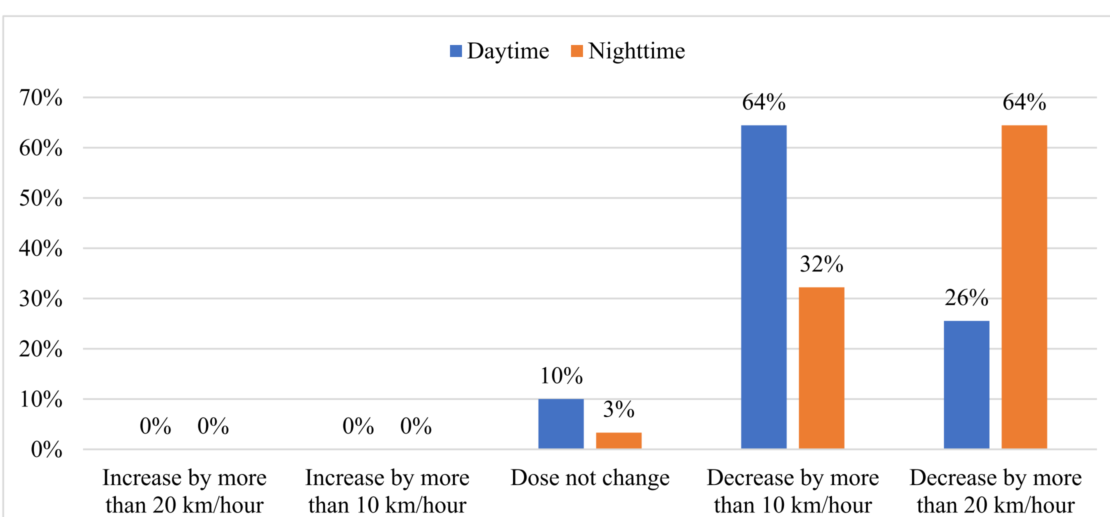

Fig. 4. Speed change when travelling through HWZs compared to normal operations.

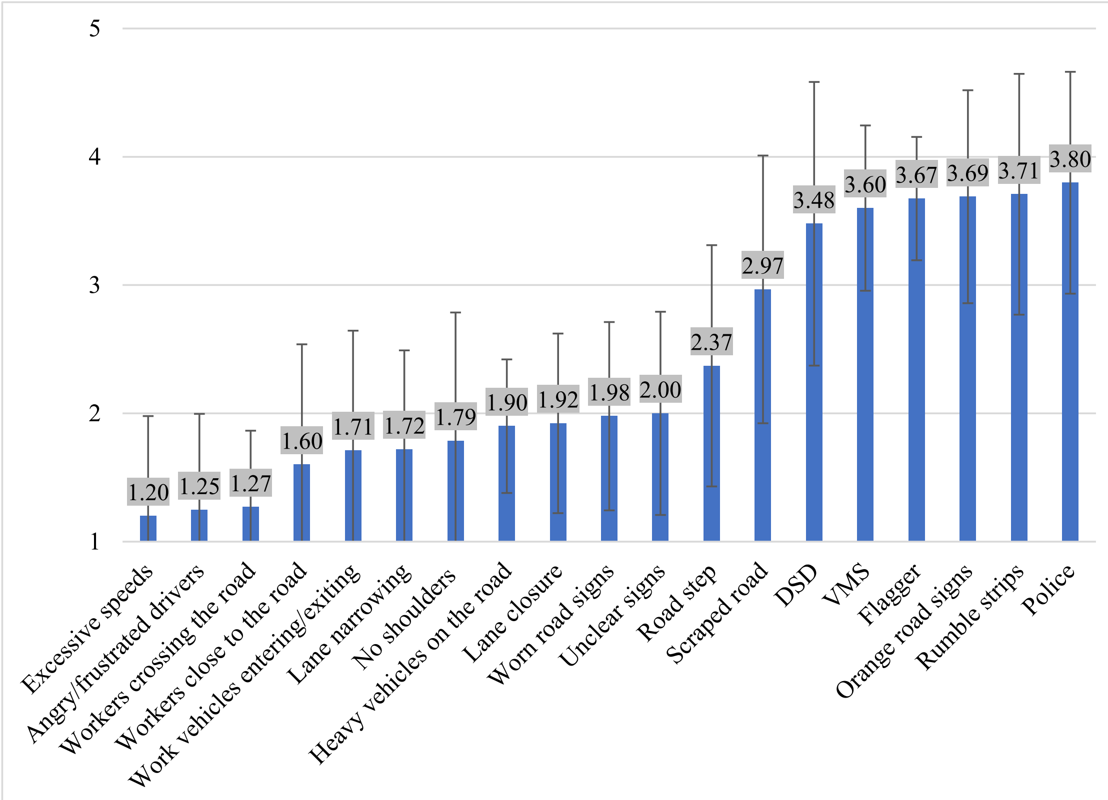

Fig. 5. Average HWZ attributes risk perception.

Table 3
Tested factors CMF value.

HWZ attributes	Average risk perception	CMF
Lane narrowing	1.72	1–1.29 (Depending on lane width)
No shoulders	1.79	1.21
Lane closure	1.92	1.26–1.9
DSD	3.48	0.98
VMS	3.60	0.84
Flagger	3.67	0.90
Police	3.8	0.56

to be three. This was based on the number of factors that had an Eigenvalues closest to one and the separation into three latent variables had the most meaningful explanation of the included variables. Table 5 presents the three latent variables, their mean and variance (among the participants), and their alpha Cronbach. Since all variables have an alpha Cronbach higher than 0.7 there is acceptable internal consistency. Furthermore, a reliability test was conducted to see if any of the latent variables will have a higher alpha Cronbach value if one of its included HWZ attributes will be removed and the results showed that none should be removed.

Personal characteristics that explain the latent variables

To find the connection between the participants' personal characteristics and their risk perception linear regressions were conducted. The linear regressions examine the effect of gender, age, and years of driving experience on the three latent variables (Table 5). The results are presented in Tables 6 and 7. Gender was the only personal characteristic that showed significant results, and only on the first two latent variables. Male drivers had 0.216 higher average score than females (1 is "the risk increases greatly", 5 is "the risk decreases greatly") for the dangerous situations' latent variable. For the guidance' latent variable male drivers had 0.394 lower average score than females. This indicates that male drivers have lower risk perception for the hazardous HWZ attributes. In contrast, female drivers have higher trust in the suggested mitigating factors. Martinussen et al. [14] showed that young males' self-assessments are inconsistent with their driving performance. This may partially explain why they have lower risk perception.

Table 4
Factor analysis results of the 19 HWZ attributes.

HWZ attribute	Factor 1 Dangerous situations	Factor 2 Guidance	Factor 3 Physical disturbances
Lane narrowing	0.36	−0.03	0.06
Lane closure	0.32	0.19	0
Workers crossing the road	0.54	−0.14	0.1
Police	0.2	0.78	0.02
Flagger	0.11	0.9	0.03
Workers close to the road	0.51	0.09	0.08
Worn road signs	0.45	0.11	−0.05
Excessive speeds	0.82	0.03	−0.12
Heavy vehicles on the road	0.58	0.14	0.08
Work vehicles entering/exiting	0.48	0.06	0.13
DSD	0.05	0.52	0.03
VMS	0.07	0.57	0.07
Scraped road	0.09	0.28	0.69
Road step	0.06	0.13	0.7
No shoulders	0.39	−0.29	0.34
Angry/frustrated drivers	0.65	0.01	0.08
Unclear signs	0.22	−0.11	0.36
Rumble strips	−0.18	0.39	0.4
Orange road signs	−0.03	0.17	0.11

Note: Factor loadings higher than 0.40 are bolded.

Table 5
Latent variables.

Latent variable	HWZ attributes	Mean	Variance	Alpha Cronbach
Dangerous situations	Workers crossing the road Workers close to the road worn road signs Excessive speeds Heavy vehicles on the road Work vehicles entering/exiting Angry/frustrated drivers	1.556	0.198	0.78
Guidance	Flaggers Police VMS DSD	3.624	0.525	0.81
Physical disturbances	Scraped roads Road step	2.647	0.936	0.71

Table 6
Regression statistics of the gender effect on the latent variables.

	Dangerous situations	Guidance
R Square	0.052	0.068
Adjusted R Square	0.042	0.057
Standard Error	0.439	0.698
Observations	90	90

Risk factor effect on driving behavior

To study the effect of the countermeasures on speed and if an association exists between the risk perceptions and the driving speed in the driving simulator experiment; the questionnaire answers and the three latent variables were added to the LMEM along with the studied countermeasures in Shahin et al. [16]. The average driving speed was 88 km/hour with a standard deviation of 18 km/hour. The results of that part show that speeds in the AWA and HWZ are lowered by 4.7 % and 12.7 %, respectively, relative to the noWZ section. HWZ strips and VMS effect at the AWA section are 7.3 % and 10.1 %, respectively. Participants between 25 and 29 years old drove 6.3 % slower than participants between 20 and 24. As described above, the eight scenarios that each participant drove through were arranged in four simulator runs. The results show that later runs are associated with lower speeds (Table 8). See Shahin et al. [16] for full details on these variables and the ones that showed statistically insignificant effect on speed. The answers for Question 9 in the questionnaire were given a 5-point Likert scale values (1 is “The risk increases greatly” through 5 is “The risk decreases greatly”). Each latent variable was integrated into the LMEM by calculating the average of the answers of its included HWZ attributes. For example, if a participant filled in the questionnaire that “scraped roads” and “road step” lead to a slight increase in risk (a value of 2) and a great decrease in risk (a value of 5), respectively, the value considered for the “Physical disturbances” latent variable in the LMEM was 3.5 (their average). Due to the relatively small number of participants a random parameter model was not statistically significant. Therefore, a random effect model where only the intercept varies was used. The LMEM results with the statistically significant countermeasures are presented in Table 8 and are as follows:

1 For driving experience in the three months prior to the experiment in HWZs, when considering each one of the five answers separately (Fig. 2) none showed significant results. Therefore, to reduce the number of variables in the LMEM the five answers were clustered into two groups (driving less than once a week and more than once). The results show that participants that drove more than once a week drove at a speed 8.8 % higher. This indicates that drivers with more experience feel more comfortable driving at higher speeds, while less experienced drivers drove more cautiously by lowering their speeds.
2 The lower the value of the dangerous situation’s latent variable the lower the speed. Every unit of increase in that latent variable was associated with an increase of 8.6 % in speed. This result indicates that the higher the perceived risk by the drivers the lower their speed.
3 The guidance latent variable alone had no significant effect on speed; therefore, it was excluded from the model. However, the interaction between VMS and the guidance latent variable is borderline

Table 7
Association between participants’ personal characteristics and the latent variables.

Latent variable		Coefficients	Standard Error	P-value	Lower 95 %	Upper 95 %
Dangerous situations	Intercept	1.414	0.080	<0.001	1.255	1.574
	Gender	0.216	0.098	0.03	0.021	0.411
Guidance	Intercept	4.161	0.221	<0.001	4.600	3.722
	Gender	−0.394	0.156	0.01	−0.084	−0.705

Table 8
LMEM results for vehicle speed in (m/s) considering the questionnaire answers.

Fixed effects		Estimate		Std. Error	P-value	Speed change
Intercept		3.155		0.066	<0.001	
AWA		−0.048		0.007	<0.001	−4.7 %
HWZ		−0.136		0.007	<0.001	−12.7 %
HWZ strips		−0.076		0.013	<0.001	−7.3 %
VMS in AWA		−0.106		0.036	0.003	−10.1 %
Age 25–29		−0.065		0.036	0.076	−6.3 %
Run2		0.036		0.007	<0.001	3.7 %
Run3		0.065		0.007	< 0.001	6.7 %
Run4		0.077		0.007	< 0.001	8.0 %
Driving more than once a week in HWZs		0.084		0.036	0.021	8.8 %
Dangerous situation latent variable		0.083		0.038	0.030	8.6 %
Guidance latent variable interaction with VMS		0.018		0.009	0.055	1.8 %
Random effects						
Residual	0.009		0.096			

significant (P-value=0.055). This result means that the higher the value of the guidance latent variable (the highest decrease in perceived risk) the higher the speed in the AWAs with VMS.

Conclusions

This research studied drivers' risk perception in efforts to mitigate these risks. A questionnaire on drivers' risk perception of typical HWZ attributes was built. The results were compared with the available CMF. Then a factor analysis was conducted to find the latent variables behind these attributes. Afterwards, in efforts to find how these latent variables are affected by personal characteristics a linear regression was conducted that examined the effect of gender, age, and years of driving experience on these latent variables. Finally, to examine if these latent variables affect driving behavior, they were integrated into a driving simulator study and their effect on driving speed was examined.

The questionnaire results showed that most participants perceive driving through HWZs in general as more dangerous and driving through HWZs at nighttime is significantly more dangerous than daytime. The most dangerous attributes perceived by drivers are excessive speeds, angry/frustrated drivers, and workers crossing the road. And, many attributes were perceived to lower crash risk including DSD, VMS, flaggers, orange road signs, rumble strips, and police. The most effective one is police presence. Moreover, the questionnaire shed some light on drivers' risk perception of several HWZ attributes that were not covered by previous studies (scraped road, road step, and orange road signs). A consistency was found between the available CMFs and the risk perception of the studied attributes. The factor analysis revealed three latent variables behind the studied HWZ attributes: dangerous situations, guidance, and physical disturbance. The effect of different HWZ attributes (than the ones studied in this research) on risk perception can be estimated based on the three latent variables found in this study. Among the studied personal characteristics (gender, age, years of driving experience) only gender showed significant effect on the latent variables, and it was only on the dangerous situations and guidance latent variables. Male drivers have lower risk perception. The results of incorporating the questionnaire with the simulator experiment suggest that more experienced drivers through HWZs drove at significantly higher speeds, and the higher the perceived risk by the drivers the lower their speed. These results can aid decision-makers in choosing safer HWZ layout operations considering drivers' risk perception. Also, since risk perception influences driving speed, increasing the awareness of HWZ risks will lead to safer work zones. The study has several limitations including relatively small sample size, most participants were young. Also, speed was the only dependent variable. Future research will include more dependent variables such as speed variance and lateral position to give more accurate indication of road safety at HWZs. Moreover, it will extend to mining workers' risk perception as well.

Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request

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CRediT authorship contribution statement

Fadi Shahin: Conceptualization, Methodology, Software, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing. **Wafa Elias:** Conceptualization, Methodology, Supervision. **Tomer Toledo:** Conceptualization, Methodology, Supervision.

Declaration of Competing Interest

None.

Data availability

Data will be made available on request.

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