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Are roadwork zones safe?

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Abstract

Increasing heavy traffic volumes and ageing of road infrastructure cause road pavement degradation, which leads to the need for repaving or rehabilitation activities – roadwork. As cars are much more enhanced than previous decade, drivers accept roadwork zone as a common condition. Work zones present more complex driving environment in consequence of possible accidents. Accidents in roadwork zones are significant problem in all European countries while noncompliance with speed limits is one of the major safety concerns. The article gives an overview of the existing traffic safety situation in roadwork zones through the EU countries. Analysis of traffic speed of different layout work zones and accidents statistics on the Lithuanian national road network is presented. Based on research this research. The most effective traffic calming measures are highlighted.

Keywords: roadwork zone; roadwork; speeding; traffic calming measures; traffic flow; traffic accident

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1. Introduction

Road operation and maintenance are the main part of road asset management. Only cost-efficient and timely repair of degraded pavements ensures optimal and balanced use of funds allocated to road maintenance, as well as cost savings for the society. However, it should be noted that any intervention into traffic lane, where works are carried out without closing of traffic, causes discomfort to the road users. Some authors indicate work zones as critical nodes of the road network in terms of road safety as they entails deviations from frequent driving conditions in a discrete road section (La Torre et al. 2017). An appropriate work zone design and planning is a major priority to increase the safety for workers and motorists otherwise without corresponding traffic control, a driver may collide with other vehicles, run off the road, or even enter the restricted areas of the work zone (Vadeby et al. 2016).

Even though motor vehicle accidents related to work zones represent only a small percentage of the total number of crashes, the phenomenon is significant and work zones can be considered as a critical point for the safety of both vehicle occupants and workers. As confirmed by statistics showing that crash rates in work zones are generally higher than those for the same sites during normal operations (Perco et al. 2012).

Human errors and excessive speed have been identified as the major causes of roadwork zone crashes (Kumar et al. 2012). The human errors can be attributed to inadequate behaviour in certain situations (driving through a red traffic light short-time signal), driver inattention (not paying attention to road signs). Adding more, there are much more surroundings in roadwork zones whose could easily distract driver. Drivers used to underestimate the danger of roadwork zone since that not all risks and hazards can be controlled absolutely. Many authors and reports (SWOV, 2010; Debnath et al. 2015; Thomson et al. 2014; Atombo et al. 2016; Domenichini et al. 2017) state that speeding is most common violation and accidents causer in roadwork zones.

2. Literature review

Scientific researches and studies (Khattak et al. 2002; Kumar et al. 2012; PRAISE, 2011) have indicated that within work zone the accident risk for road user is considerably increased. Dealing with the safety in roadwork zone, two aspects should be differentiated: safety of road users and safety of road workers. The data of FORMAT project (2005) shows that accident rate in work zones varies from 0,5 % to 4,9 % within Europe countries (FORMAT, 2005). A survey released by the UK Highways Agency in 2006 suggested that up to 20% of workers had suffered some injury caused by passing vehicles in the course of their careers and 54% had experienced a near miss with a vehicle (Perco et al. 2012). During the years 2003–2012, at least 2 435 severe crashes occurred at various types of roadwork in Sweden (Liljegren, 2014). Of the 2 435 crashes, 42 (1,7%) were fatal accidents and 519 (21,3%) were accidents with serious injuries. Similar statistics were recorded in the period 2000-2009 in Netherlands (SWOV, 2010) where an average of 18 fatal crashes (2% of all fatal crashes) occurred at work zones. In Italy, 762 work zone crashes, with fatalities or injuries, occurred within the 3000 km long motorways managed by Autostrade per l'Italia S. p.A. (ASPI) during a 6-year period from 2007 to 2012. Such crashes resulted in 21 fatalities and 1252 injuries (La Torre et al. 2017). In 2011, in Poland 11 accidents occurred in road work zones where 18 people were killed (Żochowska, 2014).

With reference to FARS/GES data (2015) the accident rate in work zones was 1,5% within US. In 2014, there were 669 fatalities from crashes in work zones. This equates to 2% of all roadway fatalities nationally (NHTSA, 2014). Out of a total of 96 626 crashes recorded within work zones in 2014 (1,56% of the total number of roadway accidents) only 0,7% led to fatalities, whereas 26,4% were injury crashes and 73% were property damage only (PDO) crashes.

All countries seek to reduce the number of accidents in road work zones by introducing innovative traffic calming measures, implementing education campaigns or instructing road workers on their behaviour in work zone. A report by the Kansas State University (Domenichini et al. 2017) indicates 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 et al. 2009), speeding was a factor in 15% of the fatal crashes and 20% of the crashes causing injuries. Drivers accepts work zone as normal section of road where there are no speed and traffic restrictions. For this reason, various traffic calming elements and measures should be used to prevent road accident occurrence. A wide variety of safety measures are used worldwide to improve speed limit compliance. These measures could be categorised based on their functional characteristics as informational, physical, enforcement and educational (Kumar et al. 2012). The informational measures procure road users to roadwork related information such as speed limits or hazard

warnings. Research by (Brewer et al. 2005) have shown that the presence of portable changeable message signs in Texas roadwork zones reduced the mean speed by 3,4 km for passenger cars and 2,1 km/h for trucks. Georgia Transportation Institute (Evaluating speed reduction… 2005) determined that the variable message sign with radar does help reduce the adjacent speed at two-lane and two-way rural highway locations. Though the speed reduction is small (ranging from 1,6 km/h to 4,8 km/h) the reduction is maintained over time as well as downstream of the sign placement. Clemson Researchers, in their study (Chowdhury et al. 2006) identified that the use of variable message signs reduces the mean speed by 6,4 km/h.

Various physical measures can be used at roadwork zones and usually they are placed on the road surface with the aim to reduce speed. The California Department of Transportation (Guidance for the… 2013) tested rumble strips in areas leading up to work zones and found that 46% of traffic slowed down, with nearly half of all vehicles slowing down by an average speed of 12.8 km/h. Other studies report smaller speed reductions of 1,8–3,5 km/h for cars (Fontaine et al. 2001) and 1,5–3,7 km/h for trucks (Meyer et al. 2000). Some countries are applying temporary lane narrowing techniques however some studies determined that too narrow lanes (less than 3.0 m) may lead to driver discomfort, difficulty in remaining within the lane and increased collisions (Harmelink et al. 2005).

Enforcement measures are used to impose speed limits by presence of police car or automated speed monitoring. The Minnesota DOT examined the effectiveness of police enforcement in work zones during 1999. The study found that the 85th percentile speed was reduced from 82,0 km/h to 69,2 km/h when a police vehicle was parked upstream of the work zone (Minn DOT 1999). In 2007 the Oregon Department of Transportation made an evaluation of an initial photo radar installation in a highway work zone (Joerger, 2010). Photo radar enforcement had a substantial impact on reducing the number of speeding vehicles in a construction work zone. Speeding was reduced by an average of about 24%.

Educational measures are used to improve road users' awareness of the risks at roadworks through public campaigns and training programs (Debnath et al. 2012). However their actual effectiveness in terms of work zone speed reduction could not be determined due largely to the lack of objective and reliable evaluations (Debnath et al. 2014).

3. Data collection and results

3.1. *Accidentology*

One of the main challenges in studying roadwork accidents is to find the right types of accidents in statistics since many accidents at roadwork zones are minor and without injuries. These type of accidents usually are not reported to police or other responsible institution but can cause problems for other road users (e.g. delays). The official statistics are based only on accidents reported by the police since all hospitals do not yet report accidents.

During the years 2012-2016 at roadwork zones at least 77 accidents occurred in Lithuania. Most likely more accidents have occurred at roadwork zones but these accidents were unreported to police. Of the 77 accidents, 1 was fatal accident and 16 were accidents with injuries. The rest of them were accidents with minor damage of vehicle or work zone equipment. There is no statistical information about road worker's injuries or deaths at roadwork zones. The traffic accident and work zone lenght curve is depicted in figure 1.

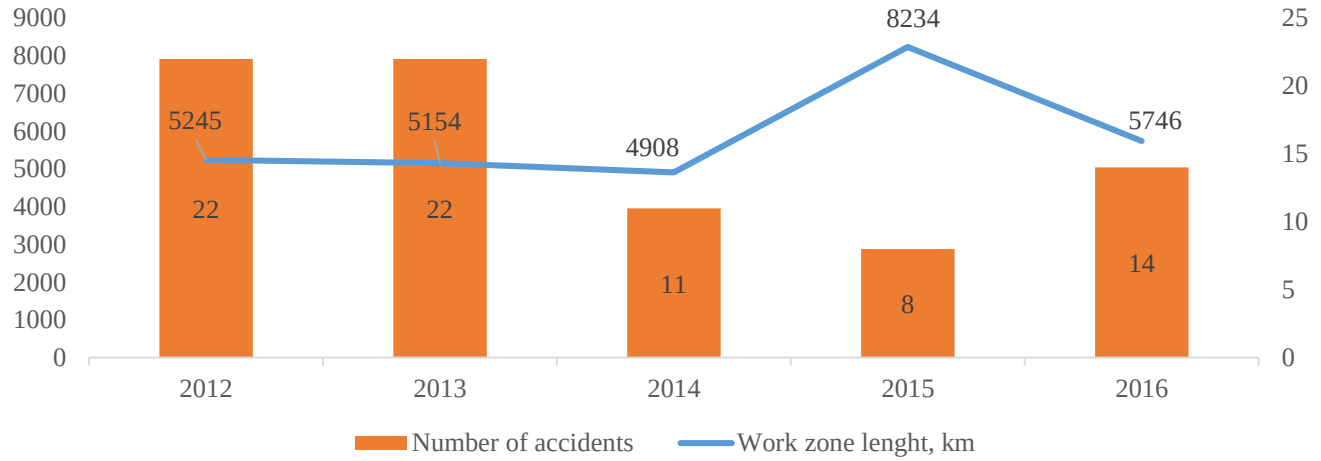

Fig 1. Number of traffic accidents at roadwork zones in Lithuania

The number of accidents from 2013 decreased steadily unfortunatelly the previous year number of accidents increased by almost 60%. However the increase is most likely a result of the fact that more accidents were reported to police or insurance companies about the harm to the vehicle or work zone equipment. The five types of traffic accidents are discernible in statistics – collisions with non-vehicular obstacles, collisions (rear-end, side, head on), accidents with pedestrians, overturns and miscellaneous accidents which do not fall in any other accident category. The data of these accidents is displayed in figure 2. Accidents in night-time accounts for one third of all work zone accidents however the number of collisions ended with injury are almost the same as in the daytime. 54% of accidents on state owned roads happen at night or late evening while on local roads or streets 75% of accidents happen at daytime. The possibility that the collision in the work zone at night will end up with injury reach 31%, while the share at daytime is slightly lower – 20%.

30% of roadwork zone accidents happen on state owned roads (highways, national roads). The rest of the accidents occur on municipal road network (local roads, city streets). Despite the fact that the accident rate on state owned roads is lower, the outcome of accidents is more severe. 40% of roadwork zone casualties fell into the accident on state roads. This is due to the fact that the speed and traffic volume is much higher on highways or national roads consequently it can be a reason why more severe crashes appear on these roads. The other reason could be improper roadwork zone enclosure without lighting, signs or poorly selected work zone layout. Also, weather conditions plays a strong role in driving environment and behaviour but proper equipment and measures at roadwork zone should help road users to comply with road traffic regulations.

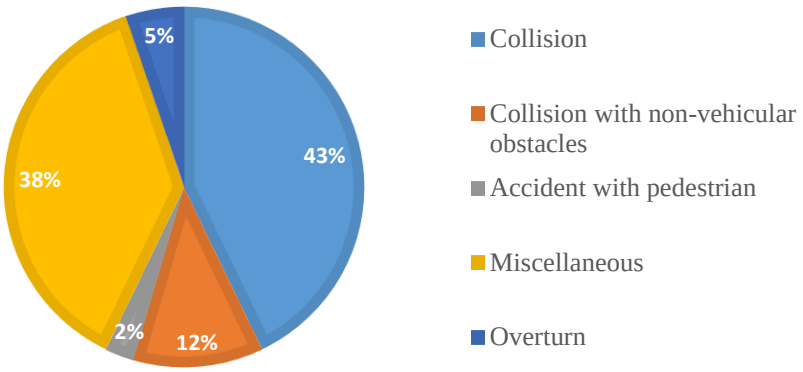

Fig 2. Types of roadwork accidents in Lithuania 2012-2016

Collision is the most common accident type at roadwork zones which acccount for more than 40% of total accidents. Accidents like collision with stopped vehicle, collision with line chaning vehicle, rear-end collision, collision with barriers, head-on collision fall into this type of accidents. The fatal accident was reported when driver crashed into road barriers at roadwork zone however this could be avoided if traffic attenuator have been installed. Most of collision forms in the transition area since most of drivers choose to change the driving lane in the last moment. On the other hand, the side collisions always end without injuries but can cause traffic queues. Rear-end crashes is most usual collision result and can happen anywhere at roadwork zone. Mostly these collisions forms in the queues in advanced warning area but there are cases when it happens due to hard braking in activity area. It is difficult to predict and avoid rear-end collisions though they often end with road user injury.

Collision with non-vehicular obstacles accounts for 12% of crashes at roadwork zone. Usually these crashes form due to disorderly equipment placing on traffic lanes. Rarely they end with injuries though it can be easily avoided if roadwork zone enclosure directions are properly followed. Although the number of overturns are not high enough but half of them end with injuries. These accidents formed at night or bad weather and there is no information about lighting installation at roadwork zone. The lack of lighting can cause more severe crashes and it is one of the reasons why accidents with pedestrians appear at roadwork zones. At long-term roadwork zones lighting must be installed nevertheless the workers are present or not.
It is difficult to draw any conclusions regarding accidents with injuries or fatal accidents since there are so few of them (16 end up with injuries and 1 fatal crash). Some of them are not typical road traffic accidents in connection to roadwork and include factors such as driving without license, drunk driving or extreme speeding. However it is clear that side collisions and rear-end collision dominates at roadwork zones and decisions must be taken to avoid these accidents.

3.2. Speeding analysis

Many authors claim that the speeding is one of the main cause of traffic accidents at roadwork zones. To convince that and find out about the real situation in Lithuania the speed at 3 roadwork zones at highway and 1 roadwork zone at national road was measured. Data collectors placed in the black boxes and mounted under the signs so that they did not distract of intenfere road users. Each data collector traced the dimensions of vehicle and speed. Four data collectors were installed in each investigated roadwork zone and the results of research are given in table 1.

Table 1. Speeding results of investigated roadwork zones

		1st data collector		2nd data collector		3rd data collector		4th data collector	
		Mean speed, km/h	% of violations	Mean speed, km/h	% of violations	Mean speed, km/h	% of violations	Mean speed, km/h	% of violations
Highway	Road No A1 (2015)	100	30,10%	82	66,40%	64	90,90%	65	94,30%
	Speed Limit, km/h	90		70		50		50	
	Road No A1 (2016)	93	95,50%	88	88,10%	63	79,00%	63	75,00%
	Speed Limit, km/h	70		70		50		50	
	Road No A2	106	61,20%	84	80,30%	69	93,20%	79	77,20%
	Speed Limit, km/h	90		70		50		70	
National road	Road No 145	74	93,10%	78	91,00%	73	95,60%	62	73,30%
	Speed Limit, km/h	50		50		50		50	

The span of speed measuring experiment was different at every roadwork zone but no less than 1 week. All roadwork zones were with different layouts and enclosures to see which traffic calming measures are the most effective. Research places were chosen to evaluate the speed of traffic on different category roads, with different traffic volume and traffic composition. The results in table 1 represents the mean speed of traffic no excepting the category of vehicle and the share of speed violations.

Some authors (Debnath et al. 2015) also investigated traffic speed at roadwork zones and found that drivers at night-time tended to violate speed limits more than during the daytime. After the study at Lithuanian roadwork zones it was determined that road users tend to violate the speed at morning and evening peak hours (6:00–8:00 AM and 4:00–7:00 PM). The average

speeds during these hours were significantly higher than the average flow rate and reached 3-6 km/h. Detailed speed results exposured that all types of vehicles violated speed rules at roadwork zone. The mean speed of passenger cars and single unit 2-axle trucks was the highest and ranged 1-5 km/h above the average traffic flow speed.

Research at various roadwork zones revealed that road users tend to violate speed limits in the sections where speed limit reduced mostly. However, it is found that passive measures (vertical speed limit signs, temporary road marking) do not restrain drivers from speed violations and other traffic calming measures are needed. A few active calming measures (speed camera, dummy camera) and passive (rumble strips, traffic island) were installed at roadwork zones to determine the efficiency of speed reduction.

Analysis revealed that dummy speed camera at roadwork approach zone reduced number of speed offenders by 17 % who were speeding more than 20 km/h above the speed limit. However, it can be concluded that dummy camera reduced the amount of high-speed violations (over 20 km/h) but increased the number of low speed violations (up to 10 km/h – 8 %; 11-20 km/h – 2 %). According to (Enforcement camera systems... 2008) dummy camera has influence to speeding but it is temporary measurement and efficiency decreases during the time. Also, a frequency of speeding up to 10 km/h can be influenced by the current legal acts of Lithuania, which make no provision for the financial responsibility of the violator of traffic rules but only warning.

Active speed cameras were placed in the beginning and in the end of the activity area to see how it helps to control traffic speed. It is found that speed camera helps to maintain a constant speed of traffic flow which do not increase in the range of its activity zone however no significant speed reduction was found. The effectiveness of this measure depends on the tolerance of speeding limits. Setting the actual speed limit with no tolerance can help to reduce speed limits extremely though there is unwritten rule that speed cameras tolerate up to 20 km/h higher speeds in Lithuania. Speed cameras were installed in activity area at all highway roadwork zones. The speed limit at these sectors was reduced to 50 km/h however results show that actual traffic flow speed range from 64 km/h to 69 km/h which is 14-19 km/h more than speed limit. Due to slipshod speed camera programing none of these offenders received a fine. Some authors (Debnath et al. 2012; Debnath et al. 2014) found that speed camera can reduce the speed by 4,7-12,5 km/h and the number of violations by 27%. Speed camera is effective tool to control speed of traffic flow but it should be well-programmed to have influence for violators.

Rumble strips were chosen as the traffic calming measure and placed in the end of roadwork zone at highway. Rumble strips were placed at the end of the work zone with the intention that drivers will adhere to the permissible speed throughout the entire activity area and not just at work space. These measures are designed to draw driver's attention before abrupt geometric changes of the road, dangerous intersections or entry into the work zone. It was determined that his measure cannot control traffic flow speed after work space since no noticeable decrease in traffic speed was observed during the research. Another measure was traffic island which was installed in the national road. Measure was chosen since the road had only 2 driving lanes and pedestrians crossing the road where roadworks carried out were noticed. The average speed at that place decreased by 11-16 km/h and the number of speed offenders reduced by 20%. The results were influenced by a living area close to the work zone and a large pedestrian flow across the road and nearby. Also, traffic island changes the trajectory of driving which force drivers to reduce driving speed.

Only a few traffic calming measures have been tested during the research however there are much more systems that could help to organise traffic and maintain speed limits at roadwork zones. After the research it is clear that speed camera restrains high speed offenders no matter if the camera is actually working or not. On the other hand, the efficiency of dummy camera suffocates during the time and drivers get used to it. Despite the fact, this kind of system helps to attract driver's attention and it's highly recommended to use in high intensity roads. Rumble strips should be placed in advanced warning area or at least at the the start of activity area. Regarding to other authors, it does not significantly reduce the traffic speed however it increases the vigilance of drivers. The traffic island should be installed at the places where pedestrian flow is expected. It slightly reduces the traffic lane width and automatically forces road users to reduce the speed. Also, it ensures much safer road crossing for pedestrians at work zone. Other measures and systems which are not mentioned in the paper could be also used. Variable message signs, optical speed bars, emotional signs or even lane width reduction could inform drivers about the upcoming work zone and force to reduce the speed. It is also highly recommended to use TMA at roadwork zones, especially where is potentially higher risk of the accident e.g. transition area. There are countries where the speeding fine is doubled at roadwork zones and it is also a tool to ensure the safe environmental for road users and workers. Speed camera (working or dummy), driver speed monitoring display or reduced lane width should be used in the activity area. The presence of police could be effective measure however it can be quite expensive and sometimes dummy police can play a role at roadwork zones. On the

other hand, the effectiveness of this tool constantly decreases, for this reason it can be used for a short part of time. Furthermore, the average speed control could be useful tool to grant the safety at work zones but as the police presence it could cost quite much. The using of one of stated measures does not ensure the compliance with speed limits though they should be combined together to form a system of traffic calming measures.

4. Conclusions

This paper aims to give a comprehensive understanding of traffic accidents and speeding violations at roadwork zones. Drivers used to underestimate they ability to control the situation in roadwork zones. For this reason almost half of accidents at roadwork zones happen due to various collisions. The major reasons of traffic accidents are speeding and lately change of lanes.

The research showed that violation of the speed limit at roadwork zones is a common phenomenon. Passive traffic calming measures including speed limit signs, cones, road marking, etc. maintain order of driving and helps to predict road users behaviour. However, these measures do not ensure that drivers comply with the speed limit.

Research of speed mode at roadwork zones results showed that active traffic calming measures including speed cameras or dummy cameras help to maintain the speed limit. The presence of dummy speed camera in roadwork zone reduced speeding by 17 %. The presence of speed camera guaranteed constant speed of traffic flow in its working zone but no significant speed reduction was found.

It was determined that rumble strips do not effect traffic speed at the end of roadwork zones. However this measure could be successfully used in the advanced warning area or at the beginning of activity area.

Traffic island could help to reduce driving speed on low-intensity roads and ensure safe pedestrian crossing the road. In order to ensure safe conditions for drivers and road workers the complex of active and passive traffic calming measures should be used at roadwork zones.

5. References

Atombo, C., Chaozhong W., Ming Z., Hui Z., 2016. “Investigating the Motivational Factors Influencing Drivers Intentions to Unsafe Driving Behaviours: Speeding and Overtaking Violations.” *Transportation Research Part F: Traffic Psychology and Behaviour* 43 (November). Elsevier Ltd: 104–21. doi:10.1016/j.trf.2016.09.029.

Brewer, M. A., Pesti G., Schneider IV W.H., 2005. “Identification and Testing of Measures to Improve Work Zone Speed Limit Compliance” 7 (2).

Chowdhury, M., Sarasua W., Ogle J., 2006. “Better Management of Speed Control in Work Zones.”

Debnath, A. K., Blackman R., Haworth N., 2012. “A Review of the Effectiveness of Speed Control Measures in Roadwork Zones”, Occupational Safety in Transport Conference, 20–21.

Debnath, A. K., Blackman R., Haworth N., 2015. “A Comparison of Self-Nominated and Actual Speeds in Work Zones.” *Transportation Research Part F: Traffic Psychology and Behaviour* 35 (November). Elsevier Ltd: 213–22. doi:10.1016/j.trf.2015.10.019.

Debnath, A. K., Blackman, R., Haworth, N., 2014. “Influence of visible work activity on drivers’ speed choice at roadworks”.

Domenichini, L., La Torre F., Branzi V., Nocentini A., 2017. “Speed Behaviour in Work Zone Crossovers. A Driving Simulator Study.” *Accident Analysis and Prevention* 98. Elsevier Ltd: 10–24. doi:10.1016/j.aap.2016.09.018.

Effectiveness of Law Enforcement in Reducing Vehicle Speeds in Work Zones. www.atssa.com/mndot.htm. Office of Construction, Construction Programs Section, Minnesota Department of Transportation, St. Paul, Minnesota, January 1999.

FARS/GES data from U.S. Department of Transportation Federal Highway Administration, Work zone management program, 2015.

Federal Highway Administration, 2013. “Guidance for the Use of Temporary Rumble Strips in Work Zones”.

Fontaine M.D., Carlson P.J., 2011. “Evaluation of speed displays and rumble strips at rural maintenance work zones”, Paper no. 01-2261.

FORMAT - Fully Optimised Road Maintenance – project, 2005. Final technical report.

Georgia Department of Transportation, 2005. “Evaluating speed reduction strategies for highway work zones (smart work zones)”.

Harmelink,M., Balsom, M., Edwards, R., 2005.“Synthesis of practices for work zone speed management”. Transportation Association of Canada.

Joerger, M., 2010. “Photo radar speed enforcement in a State highway work zone: Demonstration project Yeon Avenue”.

Khattak, A.J., Khattak, A.J., Forrest M., 2002. “Effects of Work Zone Presence on Injury and Non-injury Crashes”. Accident Analysis and Prevention, 34, 19-29.

Kumar, A., Ross A., 2012. “A Review of the Effectiveness of Speed Control Measures in Roadwork Zones”.

La Torre, F., Domenichini L., Nocentini A., 2017. “Effects of Stationary Work Zones on Motorway Crashes.” *Safety Science* 92 (February). Elsevier Ltd: 148–59. doi:10.1016/j.ssci.2016.10.008.

Li, Y., Bai, Y., 2009. “Highway Work Zone Risk Factors and Their Impact on Crash Severity”, Journal of Transportation Engineering, 135(10), 694-701.

Liljegren, E., 2014. “Traffic Accidents in Connection to Road Work in Sweden Traffic Accidents in Connection to Road Work in Sweden”.

Meyer, E., 2000. “Removable Orange Rumble Strips”, Kansas Department of Transportation.

National Highway Traffic Safety Administration (NHTSA). 2014. “Traffic Safety Facts: 2014.” *U.S. Department of Transportation*, U.S. Department of Transportation. doi:http://dx.doi.org/10.1016/j.annemergmed.2013.12.004.

Perco P., Dean S., 2012. “Driving Speed Behaviour Approaching Road Work Zones On Two-Lane Rural Roads.” *Procedia - Social and Behavioral Sciences* 53 (October): 672–81. doi:10.1016/j.sbspro.2012.09.917.

PRAISE: Preventing Road Accidents and Injuries for the Safety of Employees Road Safety at Work Zones, 2011

SWOV Fact Sheet Roadworks and Road Safety. 2010, no. July: 1–5.

Thomson, R., Peter S., La Torre F., Cocu X., Tucka P., 2014. “Speed Management in Work Zones – The ASAP Project.”

Vadeby A., Sörensen G., Bolling A., Cocu X., Saleh P., Aleksa M., La Torre F., Nocentini A., Tucka P, 2016. “Towards a European Guideline for Speed Management Measures in Work Zones.” *Transportation Research Procedia* 14. Elsevier B.V.: 3426–35. doi:10.1016/j.trpro.2016.05.302.

Żochowska R., 2014. “Improvement of Traffic Safety in Road Work Zones 2,” 3459–67.