Safety of road work zones: European and the U.S. perspective

Ali Osman Atahan[1, a], Murat Buyuk[1, b], Gulay Malkoc[2, c], Jose Diez[3, d]

[1] *Civil Engineering, Istanbul Technical University, Istanbul, Turkey*
[2] *ASMUD, Ankara, Turkey*
[3] *European Union Road Federation, Brussels, Belgium*

[a] atahana@itu.edu.tr
[b] mbuyuk@gmail.com
[c] gulay@asmud.org.tr
[d] j.diez@erf.be

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ABSTRACT

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Unfortunately, the proper treatment for work zone area in Europe and the US are still overlooked by concerned authorities. Inadequate and improper selection of traffic control devices can be generally seen in some maintenance sites. Lacking of consistency and knowledge in designing proper traffic control plan can also be noticed. The improper use and arrangement of protective control devices within work zone such as unprotected work space without proper protection devices, loose debris and construction material on the roadway, and discontinuous barriers to prevent errant vehicles can be widely observed.

This paper presents and compares the key elements for the work zone safety in Europe and the US. It focuses on particularly functional and physical separation between workers and traffic, preservation of traffic flows and clarity in the directives and relevance of the information. Moreover, human targeted solutions, sustainability and safety aspects obtained from European and US road work zone projects are also addressed.

Keywords: European infrastructure policy, Risk analysis, Risk management, Safety

KEY ELEMENTS OF WORK ZONE SAFETY IN EU AND US

Ömer Faruk AYDIN[1], Gülay MALKOÇ[2], Murat BÜYÜK[3], José DIEZ[4], Ali Osman ATAHAN[3]

[1] Research Assistant, Boğaziçi University, Department of Civil Engineering, Bebek, Istanbul.
[2] Head of Health and Safety Division, European Asphalt Pavement Association, Brussels.
[3] Istanbul Technical University, Department of Civil Engineering, Ayazağa, Istanbul.
[4] Director of Public Affairs and Communication, European Union Road Federation, Brussels.

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1. INTRODUCTION

Rapidly-developing metropolitan cities across the world have brought numerous substantial problems, an important one of which is the transportation problem. For this reason, highway facilities have been constructed for decades in all civilized areas. At this time, most of these facilities require maintenance which creates increasing number of work zones. Work zone is defined as the section of a road that influenced by any construction works occurring in the area. Interruption of normal traffic flow due to work zones causes many significant safety issues. Therefore, studies on work zone traffic safety are conducted to maintain maximum safety and mobility while minimizing casualties.

There are several important agencies around the world trying to fight for maintaining safety in work zones by collecting data, studying for developing feasible solutions, publishing resources to guide roadway owners. Federal Highway Administration (FHWA) of US Department of Transportation developed National Highway Work Zone Safety Program (NHWZSP) in order to maintain safety and decrease the number of crashes and fatality rates (FHWA 2014). In this context, FHWA provides comprehensive information to transportation construction industry and general public through National Work Zone Safety Information Clearinghouse (NWZSIC). This information includes accident and crash data, best practices, latest technologies and equipment, contact information of traffic safety experts, laws and regulations, safety standards publications and educational materials. On the other hand, European Union Road Federation (ERF) initiated work zone safety program in order to increase safety during road construction works by raising public and governmental awareness, conducting researches on national guidelines, legislations and case studies, and helping standardization work zone safety program in European countries (ERF 2015).

Although many studies on this aspect are being conducted, work zones still remain as hazardous zones which cause considerable amount of fatalities each year. The main reason of work zone crashes is unexpected change of normal driving environment. Despite drivers mostly don’t consider work zones to be dangerous areas, the collected data from various countries shows the importance of the situation. National Highway Traffic Safety Administration (NHTSA) of the US reported 579 fatalities occurred in the US work zones in 2013. In other words, in 2013, nearly 2% of the total fatalities in motor vehicle traffic crashes (32,719 total fatalities) occurred in work zones (FARS, 2013). Meanwhile, 2% of the total fatal crashes happened in work zones also in Netherlands in the period of 2000-2009 (SWOV, 2010).

There are some methodologies used by the authorities to provide safety in work zones. These methodologies basically try to identify the nature and scope of the safety issues including determining the risk factors that cause accidents and crashes and then eliminate or diminish consequences of these risks. To begin with, designers should understand the dynamics of work zone safety and design the work zone to minimize risks e.g. separating traffic and construction area by designing clear zones, buffer spaces and positive protection devices. The level of the risks is affected mainly by several reasons, namely, time phase and placement of work zone, duration of the works, road types and parts of the work zone. After risk analysis, proper equipment are selected related to functional analysis of the equipment e.g. restraint systems, delineators, warning lights, vertical lights, temporary markings, etc. At the last stage the risks are re-evaluated to ensure that precautions are satisfying for eliminating the risks or at least reduce the dangers to an acceptable level. Besides of mentioned safety methodologies, designers continue researches to find new innovative solutions and develop the existing ones for increasing safety conditions.

This study aims to contribute work zone safety and decrease fatality rate in the future by presenting the key elements of work zone safety to authorities and awakening public awareness. To support the main objective of this study, background information on work zone safety is given in the next section. In the mentioned section, design guide of clear zones, buffer spaces and positive protection equipment of FHWA is examined, then, risk assessment and risk reduction methodology of ERF is summarized to show how work zone safety is tried to be maintained in European countries. Additional innovative studies on work zone safety are also mentioned in this section. Later section, some application examples around the world is presented to see how the risk methodology works in real life situations. In the last section, conclusions of this study are summarized and suggestions are made in order to help improving work zone safety.

2. BACKGROUND INFORMATION ON WORK ZONE SAFETY

In recent years along with many agencies ERF of Europe and FHWA of US pay serious attention on work zone safety. Besides work zone safety studies, FHWA distribute Federal-aid funds to all state highway agencies provided that process reviews are prepared by them in every two years. In 2014, FHWA published a paper, namely "Use of Work Zone Clear Zones, Buffer Spaces and Positive Protection Deflection Distances", to guide work zone designers and workers by summarizing available guidance on work zone clear zones, buffer spaces and positive protection distances (FHWA 2014). All involved parties are instructed to follow this guidance to understand the role of separation distances, positive protection equipment and how to install, maintain and use them in work zones. On the other hand, in 2011, ERF summoned a dedicated working group dealing with national guidelines, legislations and cases regarding safety equipment to be able to improve safety and to find best practices. For this purpose, the working group collected detailed data from Trans-European Transport Network (TEN-T) sections in various countries e.g. Germany, France, Italy, Belgium, Spain and Austria.

2.1. Design of Work Zone Clear Zones, Buffer Spaces and Positive Protection Deflection Distances

Work zones are generally divided into two spaces as shown in Figure 1; (a) traffic spaces where traffic is allowed to flow and (b) work spaces where construction works are performed. Most of the accidents, which results in severe injuries and deaths, happen as a result of road users engaging work spaces or workers engaging traffic spaces. FHWA's clear zone guidance is published to come up with these problems.

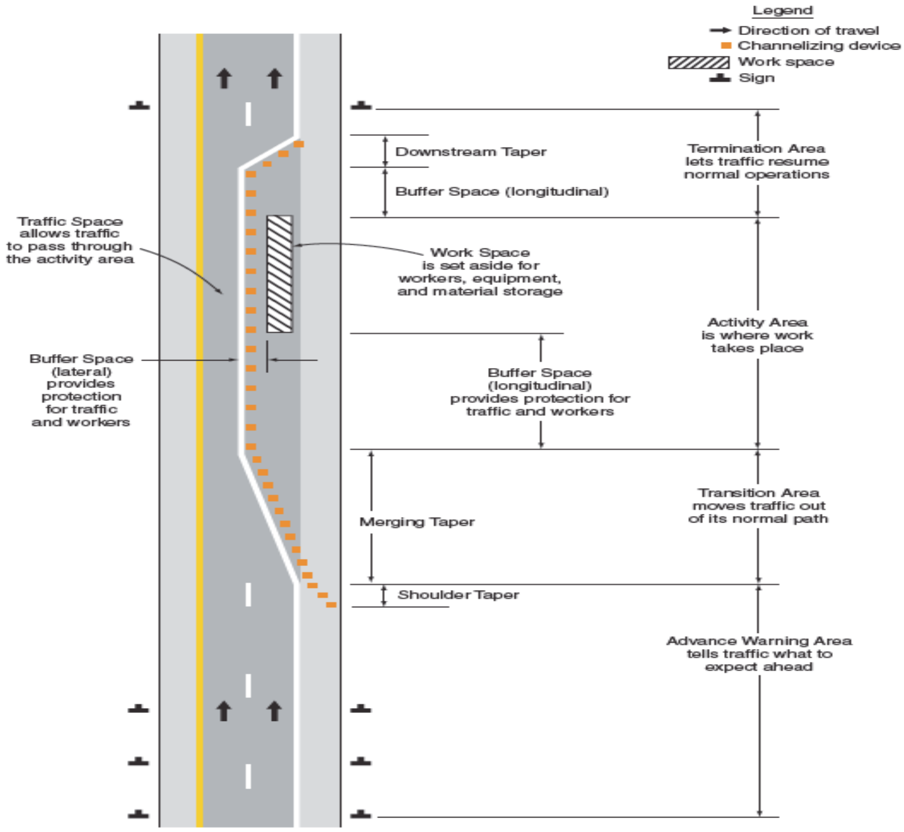

Figure 1. Traffic Space, Work Space and Buffer Spaces
(Source: Manual on Uniform Traffic Control Devices, FHWA)

According to FHWA work spaces and traffic spaces can be separated mainly in two ways:

1- By using traffic barriers and other positive protection devices,
2- By increasing distance between these two spaces.

The choice between these two methods is made based on following factors; (a) width of the road, (b) expected demand of the road, (c) expected duration of construction works, (d) traffic control methods (e) traffic speed.

Clear zones and buffer zones are both have the same main objective that is providing enough space for an errant vehicle to safely stop and/or recover back to the normal lane. The differences between these two terms are clear zone being applied to hazards other than equipment currently in use during a particular shift and measured laterally while buffer zone being implemented during construction activity and measured both laterally and longitudinally. Clearly, when clear zones and buffer space distances increase, the possibility of an errant vehicle to leave the normal lane decreases. Figure 2 shows this probability for given distance.

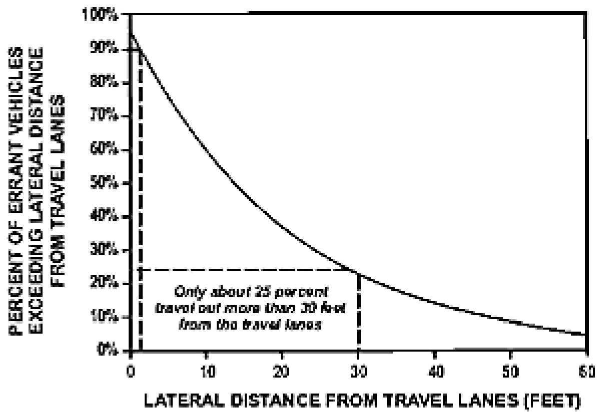

Figure 2. Errant Vehicle Lateral Distance Travel on Multilane Highways
(Source: Roadside Safety Analysis Program (RSAP), TRB)

As seen in Figure 2, only 25% of errant vehicles leave out more than 30 feet from the normal traffic lane. Leaving 60 feet will decrease the probability nearly 0%. However, most of the time the space is limited and also there should be enough space for work activities to be done in feasible conditions. Some state agencies have established clear zone distances while others have adopted ASSHTO Roadside Design Guide. Some examples of clear zones applied by the states are given in Table 1.

Table 1. Work Zone Clear Distances Used by Some States of the US

Florida DOT	**Work Zone Speed (mph)**	**Distance to Travel Lanes (ft)**	**Distance to Auxiliary Lanes (ft)**	
	60-70	30	18	
	55	24	14	
	45 - 50	18	10	
	30 - 40	14	10	
	Curb/gutter sections	4 ft beyond curb	4 ft beyond curb	
Illinois DOT	**Work Zone Speed (mph)**	**Average Daily Traffic (ADT)**	**Front Slopes (ft)**	**Back Slopes (ft)**
	< 35	< 750 750 - 1500 1500 - 6000 > 6000	4 - 6 6 - 10 6 - 10 10 - 12	4 - 6 6 - 8 8 - 10 10
	35 - 50	< 750 750 - 1500 1500 - 6000 > 6000	6 - 10 10 - 14 10 - 16 12 - 18	4 - 8 8 - 10 8 - 12 10 - 14
	55	< 750 750 - 1500 1500 - 6000 > 6000	6 - 12 10 - 16 12 - 18 14 - 20	6 - 8 6 - 12 10 - 14 10 - 16
	60	< 750 750 - 1500 1500 - 6000 > 6000	10 - 16 12 - 20 16 - 24 18 - 28	6 - 10 8 - 14 10 - 16 12 - 18
	65	< 750 750 - 1500 1500 - 6000 > 6000	12 - 16 16 - 22 18 - 26 18 - 28	6 - 10 8 - 14 10 - 18 14 - 18
Washington State DOT	**Work Zone Speed (mph)**	**Distance from Traveled Way (ft)**		
	≤ 35	10		
	40	15		
	45 - 55	20		
	≥ 60	30		
Vermont DOT	**Roadway Type**	**Work Zone Speed Limit (mph)**	**Distance from Traveled Way (ft)**	
	State/US Routes	All	10	
	Interstates *	30 - 40	13	
		45 - 50	16	
		55	23	
		60 - 70	30	
	*Vermont follows criteria in Table 9-1 of the *Roadside Design Guide* [2]			

(Source: Work Zone Clear Zones Guidance, FHWA)

While using barriers, clear zones still should be calculated since there is deflection of the barriers during any crashes. The amount of deflection of barrier depends on following factors: (a) type of barrier, (b) length of barrier, (c) connection type of barriers, (d) anchorage conditions, (e) possible speed of the crashing vehicle, (f) angle of impact and (g) mass of the vehicle. Design of work zone is made by considering the deflection of barriers some of which is summarized in Table 2.

Table 2. Traffic Barrier Service Concrete Deflection

Manufacturer	Device Description	Test Level	Dynamic Deflection	Anchorage (a)
Midwest Roadside Safety Facility	Steel strap tie-down system for PCB on bridge decks	TL-3	3' - 2"	46'
Barrier Systems, Inc.	Temporary steel barrier	TL-2 TL-3	3'- 5" 6' - 4"	52' - 6" 105'
CalTrans	4 m (13') long single-slope barrier with double pin & loop connection	TL-3	2' - 5"	85' - 4"
Oregon DOT	42" Tall – 12.5'Lg. F-Shape precast concrete barrier w/pin & loop connection	TL-3 TL-4	2'- 9" 2'- 9"	125' 100'
Indiana DOT	10' Long F-Shape barrier w/pin& loop connection	TL-3	5'- 3"	36'
Pennsylvania DOT	12.5' Long F-Shape temporary barrier w/plate connection	TL-3	8'- 7"	80'
Barrier Systems, Inc.	Steel Reactive Tension System (SRTS) Concrete Reactive Tension System (CRTS)	TL-3 TL-3	2'- 4" 2'- 0"	266' - 8"
Barrier Systems, Inc.	Quickchange Moveable Barrier (QMB)	TL-3	4'- 6"	10'- 4"
Gunnar Prefab AB	GPLINK precast temporary concrete barrier	TL-3	5'- 10"	*
Virginia DOT	20' Long F-Shape barrier w/pin & loop connection	TL-3	6'	60'
Easi-Set Industries	12' Lg. And 20' Lg. F shape barrier w/J-J hook connection	TL-3	4'- 4"	69' - 7"
Rockingham Precast	12' Long F-Shape w/T-Bar connection	TL-3	3'- 10"	60'
University of Nebraska - Lincoln	9'- 4" Long F-Shape barrier w/pin & loop connection	TL-3	6'	11' - 5" Run-on 9' - 10" Run-off
Barrier Systems, Inc.	Narrow Quickchange Moveable Barrier	TL-3	2'- 11"	(b)
Texas A&M (TTI)	Low-Profile Concrete Barrier for Work Zones	TL-2	5"	(c)

* No published information is available.
a – Anchorage is defined as the additional length of barrier needed, upstream and downstream of the work zone, to ensure the system does not exceed the maximum dynamic deflection noted in the adjacent column.
b – System was anchored using two 6" steel tubes and two 1" by 4" steel straps w/turnbuckles.These were attached to two 3' diameter by 8' deep reinforced concrete anchors.
c – System was anchored using a non-crashworthy end treatment. System must be terminated outside of clear zone or shielded with a crashworthy device.

(Source: Virginia Work Area Protection Manual, Virginia DOT)

Longitudinal Buffer Spaces are also calculated for stopping an errant vehicle before it reaches work zone. Table 3 is given in US National Manual on Uniform Traffic Control (MUTCD) presenting stop sight distances as a function of speed.

Table 3. Stopping Sight Distance as a Function of Speed

Speed, mph*	20	25	30	35	40	45	50	55	60	65	70	75
Distance, ft	115	155	200	250	305	360	425	495	570	645	730	820

(Source: Manual on Uniform Traffic Control Devices, FHWA)

All clear zones, buffer spaces and positive protection devices used for separating traffic flow and construction area and keeping an errant vehicle off the work zone should be designed based on regulations. Designers should also keep in mind that if there will be any changes, all calculations and design should be revised (FHWA, 2014).

2.2. Risk Assessment Method for Work Zones

When ERF experts conducted the TEN-T Road Network study, the most common equipment is analysed based on general types of functionality e.g. information, guidance and protection. After that risk assessment is made to ensure if the equipment helps improving safety conditions. Risk assessment and risk reduction methodology of the EN ISO 12100 consists of five phases (ERF 2015):

1. Determining the operation boundaries and any possible misbehaviour,
2. Identify the hazards,
3. Estimate the risks for each identified hazards,
4. Eliminate the hazard or reduce the risks
5. Re-evaluate.

At the first phase operation boundaries are examined related their (a) usage e.g. traffic related hazards, work force, drivers, passengers, emergency teams, media, authorities and awareness level of involved parties, (b) time e.g. before, during, after, (c) space e.g. work area, carriage way, neighbourhood, congested area and (d) other factors e.g. extend of the work area, dust, mud, weather conditions, visibility etc.

At the second stage, hazards related work force, road users and traffic flow are identified. This stage is of importance since a misidentification of these components result in inefficient safety measures and thus wastes of time and funds.

At the third stage, one of mathematical risk assessment methods (Kinney or Procter) is applied to evaluate severities of the risks. ERF used Procter method for TEN-T Project. Risk parameters and calculation method of Procter are given in the Table 4.

Table 4. Procter Risk Assessment Lookup Table

LO (Likelihood of Occurrence)		
0,033	Almost impossible	Only in extreme circumstances
1	Highly unlikely	Though conceivable
1,5	Unlikely	But could occur
2	Possible	But unusual
5	Even chance	Could happen
8	Probable	Not surprising
10	Likely	To be expected
15	Certain	No doubt

FE (Frequency of Exposure)	
0,5	Annually
1	Monthly
1,5	Weekly
2,5	Daily
4	Hourly
5	Constantly

HRN	Risk
0-5	Negligible
5-50	Low, significant
50-500	High
Over 500	Unacceptable

HRN = LO x FE x DPH x NP

DPH (Degree of Possible Harm)	
0,1	Scratch or bruise
0,5	Laceration or mild ill-effect
2	Break of minor bone or minor illness (temporary)
4	Break of major bone or major illness (temporary)
6	Loss of one limb, eye, hearing (permanent)
10	Loss of two limbs or eyes (permanent)
15	Fatality

NP (Number of Persons at risk)	
1	1-2 persons
2	3-7 persons
4	8-15 persons
8	16-50 persons
12	50+ persons

(Source: Pilz Guide to Machinery Safety, 6th Edition)

As seen on Table 4, Procter constants are determined by looking at tables of Likelihood of Occurrence (LO), Frequency of Exposure (FE), Degree of Possible Harm (DPH) and Number of People at risk (NP). As soon as these constants are known, HRN number is acquired by multiplying these numbers and risk is evaluated based on HRN. Application example of Procter method is given in the next section, namely Application Examples around the World.

After performing the risk analysis as mentioned above, the next phase includes eliminating the hazard or reducing the safety risks at work zones. This phase incorporates the following four steps:

1. Designing inherently safe measures, in other words, taking precautions in the early phases of design.
2. Safeguarding and/or complementary protective measure e.g. considering reasonably foreseeable misuse and taking precautions for this situation.
3. Information for use (warnings, signals) meaning declaring the risks in information for use if the risks still exists after Step 1 and 2.
4. Enforcement is applied by installing procedures to enable in-service monitoring and evaluation.

The final phase of risk assessment and risk reduction methodology is the re-evaluation. The following criteria are rechecked to verify the success of risk reduction:

- All conditions and interventions have been examined;
- Hazards are eliminated or risks are diminished to an acceptable level;
- Any hazards caused by protective precautions have been addressed;
- All parties are properly informed and warned;
- Precautions are compatible to each other;
- Adequate precautions are considered that can arise from nonprofessional context;
- Precautions don't harm working conditions of the involved parties.

An example risk evaluation chart is shown in Figure 3 given below.

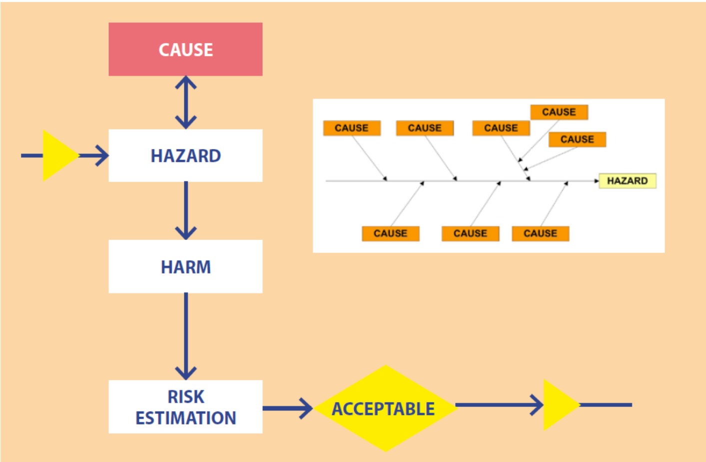

Figure 3. Risk Evaluation Chart

2.3. Innovative Work Zone Safety Solutions

Besides of designing clear zones and determining safety equipment, there are also additional safety measures applied to decrease injuries and fatalities in work zones. One of these measures is educating drivers to make them more careful while passing work zones.

In addition to these measures, semi-stationary speedometers were started to be used in some busy roads in France for increasing safety level by applying traffic enforcement solutions. Since these kinds of systems are found to be very efficient, new innovative high-tech devices are started to be used in the European roads (World Highways, 2013).

3. APPLICATION EXAMPLES AROUND THE WORLD

In recent years, ERF Working Group carry out researches on work zone safety by observing real life situations mostly occurred in Europe. As a part of these researches, the working group evaluated the pertinence of the equipment used in real life cases for work zone safety by making a risk assessment. This is done on the basis of one of the most obvious and expected event of workers hit by a vehicle. This incident may occur in two ways e.g. (1) vehicle entering the work zone or (2) worker entering the traffic. Cause-to-Effect Diagram examples of these situations are given in Figure 4 and 5, respectively.

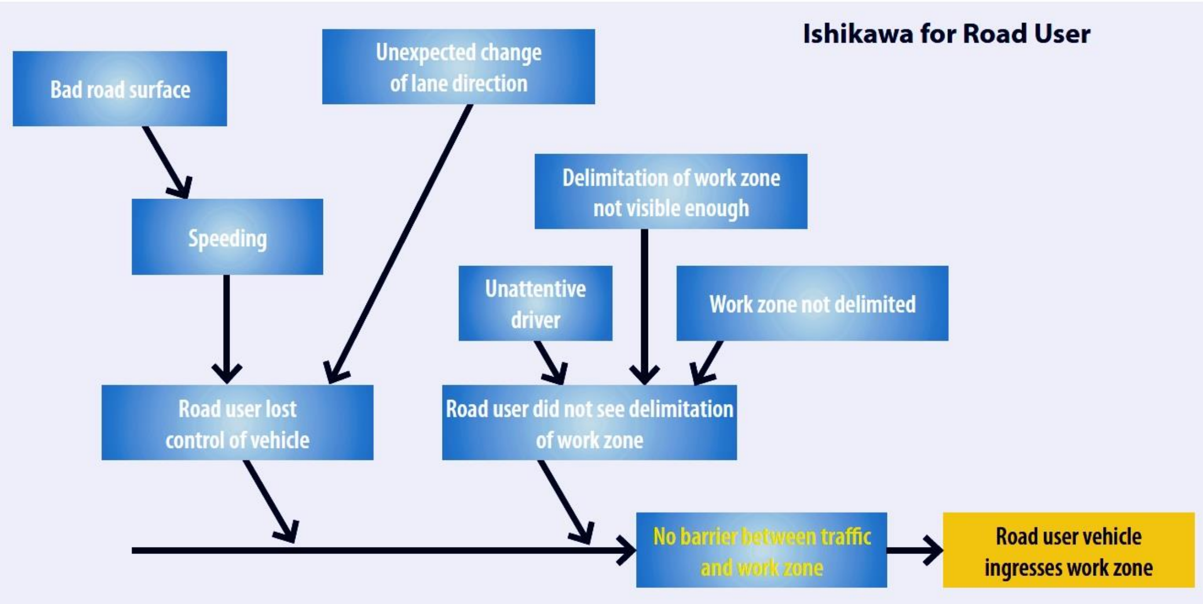

Figure 4. Cause-to-Effect Diagram for Vehicle Entering Work Zone

In Figure 4, all important possible causes of a vehicle to enter a work zone and cause-to-effect relationships are shown. For example, unexpected change of lane caused by existence of a work zone in the area may lead a driver to lose control of the vehicle. If there is no barrier separating traffic and the work zone, consequently, the vehicle may ingress the work zone. Similarly, if delimitation of work zone is not visible enough then this may cause a driver not to see delimitation of work zone and again if there is no barrier then the vehicle may enter the work zone.

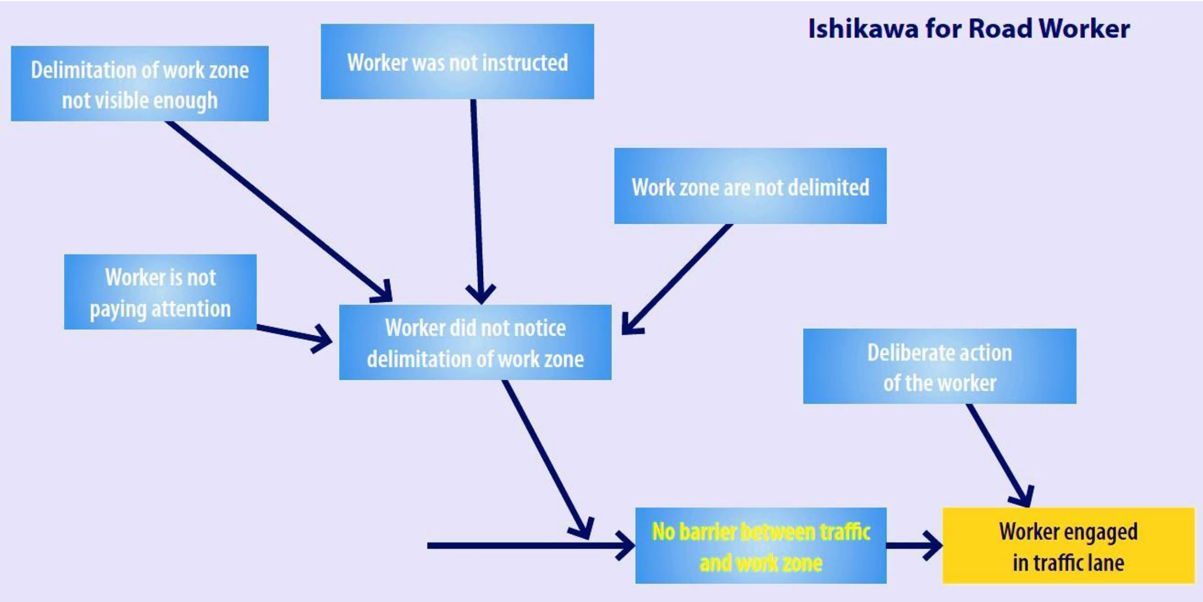

Figure 5. Cause-to-Effect Diagram for Worker Entering in Traffic Lane

Similar to Figure 4, basic possible reasons of a worker engaged in traffic lane are shown in Figure 5. For instance, if workers are not instructed they may not notice delimitation of work zone and if there is no barrier the workers may enter the traffic.

After the cause-to-effect diagrams, shown in Figure 2 and 3, are drawn, a risk assessment table is prepared, shown in Table 5. This table includes the causes determined in the cause-to effect diagrams and hazards related to these causes. After that, Procter risk constants are given considering these hazards. Based on HRN risk factor, acceptability of the risk level is determined. If the risk level is found to be unacceptable, some safety measures are taken. An illustration of this process is given in Table 5.

The risk of worker entering traffic area is taken from the cause-to-effect diagram shown in Figure 3 and put into Table 2. The principal hazard related to this cause is worker being hit by a vehicle. In this case all degree of injury becomes possible. After this point, Procter Risk Assessment Lookup Table given in Table 1 is taken as reference while determining risk coefficients. For example, Likelihood of Occurrence (LO) of this event is considered as "Probable" meaning LO coefficient to be "8". Similarly, Frequency of Exposure (FE) is constant, Degree of Possible Harm (DPH) is fatal and Number of Persons at risk (NP) is between 3 and 7. Giving coefficients accordingly and HRN is found to be 1200 by multiplying them e.g. 8x5x15x2=1200. According to EN ISO 12100, 1200 HRN means unacceptable risk. As a first action plan, planning safety perimeters, indication of parameters such as cones, delineators and instructions to the workers results in decrease in likelihood of occurrence and relatedly decrease in HRN number to 300, which means still high level of risk. Then, the second plan, separating work zone and traffic by using physical barriers causes degree of possible harm coefficient to be "0" which leads HRN to be "0" and negligible risk level. As a result, by applying safety risk plan and taking appropriate safety precautions, work zone safety is maintained for these situations.

Table 5. Risk Assessment Table

			Risk evaluation (Procter)						Step 1 (Protective measures)	Step 2 (information for user)	Step 3 (Information for user)	Reassessment of the risk						
			LO	FE	DPH	NP	HRN	Risk level				LO	FE	DPH	NP	HRN	Risk level	Addressing residual risk
Causes	Hazards (5.4)	Harm																
WORKER																		
Worker engaged in traffic area	Worker being hit by road user vehicle	All degree of injured	8	5	15	2	1200	Unacceptable	Plan safety perimeter	Indication of perimeter (cones, delineators, ...)	Instructions to the workers	2	5	15	2	300	High	Instructions to the workers
									Plan work zone and traffic in separate areas	Physical separation (barriers)	Instructions to the workers	1	5	0	2	0	Negligible	Instructions to the workers
ROAD USER																		
Road user vehicle ingresses work zone	Worker being hit by road user vehicle	All degree of injured	8	5	15	2	1200	Unacceptable	Plan work zone and traffic in separate areas			1	5	0	2	0	Negligible	Equipment performance
									Organise a fixed safety perimeter	Separation markers (beacons, cones, cilinders, delineators, barriers, fences,...)	Conspicuous separations	1	5	4	2	40	Low significant	Equipment performance
									Lower traffic speed	Humps	Speed limitation signs	5	5	4	2	200	High	Conspicuous speed enforcement, equipment performance
									Channelise traffic (if a fixed safety perimeter is not practicable)	Delimitation markers (beacons, cones, cilinders, delineators, barriers, fences,...)	Conspicuous separations	2	5	15	2	300	High	Equipment performance
									Organise driver awarness		Advance signs, warnings	2	5	15	2	300	High	ITS

4. CONCLUSIONS & RECOMMENDATIONS

As a rapidly increasing problem of modern world, the transportation brings very serious safety issues. An important one of these safety issues is work zone safety which disrupts normal traffic flow either by changing highway geometry or closing lanes. These unexpected changes in normal traffic condition due to work zone safety bring severe safety challenges. There are many researches conducted on this subject in the recent years in order to maintain maximum safety and mobility and minimize casualties and fatalities.

Nearly 2% of the total fatalities happened in motor vehicle traffic crashes occurred in work zone areas. Many agencies around the world work for diminishing fatalities in work zones. In this context FHWA of US developed National Highway Work Zone Safety Program and provides comprehensive information to the general public through National Work Zone Safety Information Clearinghouse. Besides, ERF of Europe also initiated work zone safety program to fight with work zone safety problems by finding best practices. This study presents key elements of work zone safety by examining researches and case studies, mainly conducted by these agencies.

Inadequate and improper choice of safety equipment can be seen on the maintenance sites most of the time. Lack of consistency and design knowledge also increase severity of safety problems. Additionally, improper use/arrangement of protection equipment, loose debris, construction material on traffic flow area and discontinuous barriers are widely observed faults in work zones. FHWA published a design guide for clear zones, buffer spaces and positive protection devices. These parameters are determined by considering (a) width of the road, (b) expected demand of the road, (c) expected duration of construction works, (d) traffic control methods (e) traffic speed. Clear distances, amount of barrier deflections and buffer spaces are determined by Department of Transportation and may differ from state to state in US. While designing or revising a work zone in the US, designer follows these regulations by considering mentioned factors of the work zone.

In 2011, ERF summoned a working group to examine national guidelines, legislations and cases regarding safety equipment. Following this objective, the working group collected detailed data from Trans-European Transport Network (TEN-T) sections in various countries around the world.

The risk assessment and risk reduction methodology used to investigate the case study presented in this paper consists of five phases: (1) Determining the operation boundaries and any possible misbehaviour, (2) Identifying the hazards, (3) Estimating the risks for each identified hazards, (4) Eliminating the hazard or reduce the risks and (5) Re-evaluating the new condition. After determining operation boundaries, any possible misbehaviour and the related hazards, a mathematical risk assessment method is applied to criticize severity of the risks.

The risks of the Ishikawa case study are evaluated based on methodology of EN ISO 12100 by using mathematical method of Procter. This paper especially focuses on functional and physical separation between workers and traffic, preservation of traffic flows and clarity in the directives and relevance of information. In this context, two main possible misbehaviour and related hazards are reviewed, namely vehicle entering the work zone and worker entering the traffic. Cause-to-effect diagrams are prepared to see the hazards, a risk assessment table is prepared which includes the causes determined in the cause-to effect diagrams and hazards related to these causes. Procter risk constants are assigned considering the hazards shown in the table and HRN risk factors are determined. HRN risk factors are used to determine acceptability of the risk level. If the risk level is found to be unacceptable, some safety measures are taken. For example, by looking at Table 2, one can say that the risk level of a worker hit by a vehicle in the traffic area is unacceptable. To be able to reduce this risk level, planning safety perimeters, placing parameters like cones, delineators and instructions to workers are proposed and HRN factor is calculated again. Since the new HRN factor is also insufficient to comply requirement, separating work zone and traffic by using physical barriers instead of using cones and delineators are proposed. Recalculation based on this upgrade shows that the requirement will be satisfied by taking this precaution. In this way, appropriate safety measures can be selected by using a mathematical risk method and consequently, crashes and fatalities can be reduced.

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