Impact assessment of road work zones in operating conditions, safety and user costs

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Once built, a road network needs the preservation of its different components (pavements, bridges, signalization and safety equipment, among others), namely through a rational strategy of conservation and rehabilitation over its lifetime. Therefore, maintenance actions are needed on the network in order to overcome the degradation and the deficiencies of it.

Such actions modify the traffic and road environment conditions offered to users on a specific part of the network even if on a temporary basis, creating the so call “work zones”. The impact of these zones in the operating conditions, safety and user costs, is addressed by this study with the purpose to support strategies, practices and methodologies to minimize the impacts. The study takes into account the Portuguese reality and is supported by other experiences, given in the end the framework to deal with the impact of these zones.

Keywords: Maintenance and Rehabilitation Strategies, Risk Management, Life Cycle Cost Analysis, Road and airfield Safety, Case studies.

Introduction

For a consolidated road network as the Portuguese one, the maintenance actions allows to address the deficiencies identified in it, ensuring the provision of an adequate infrastructure service to users. The performance evolving of the different type of such actions along the infrastructure life time makes is necessary to study the impact that road work zones may have on operating conditions, road crashes and user costs, since these areas change locally and temporarily the traffic conditions offered to users (lower speeds, presence of work equipment and workers, narrow lanes, changes in vertical and horizontal signs, etc.). These conditions may cause the occurrence of serious traffic delay, car crashes and casualties, and the increase of road user costs.

Work Zone Impacts Assessment

Impact on operating conditions

When maintenance works are running in a section of a road, a reduction in capacity, calculated according to the duration and nature of the planned work, must be considered.

Several studies, based on the collection of freeways work zones data, have developed speed-flow and capacity models with incorporation of work zone configuration factors as the number of work zones, geometric alignment, work zone speed limit and work zone length (Transportation Research Board, 2010) (Weng & Meng, 2015).

The Highway Capacity Manual 2010 (HCM2010) presents default values for road capacity that can be considered in work zones. These values are presented by Chatterjee et al. (2009) and were supported in studies conducted in several US states' DOT (Department of Tranportation).

For short-term works (hours, days), a capacity of 1600pc/h/ln (passenger car/hour/lane) is considered regardless the lane close configuration. This value can be adjusted due to the effect caused by the presence of heavy vehicles in the traffic flow, due to the proximity of an entrance ramp in the tapering area or near the work zone (within 150m downstream of the beginning of the full lane closure), and due to the intensity of the activities taking place in the work area (± 10% variation depending on the number of workers on the site, the number and size of work vehicles in use, and the proximity of the work activity to the travel lanes).

For long-term work (weeks, months, years), usually associated with heavy construction activities, due to the different and specific characteristics that can be found in work zones, a significant variation in the capacity figures have been observed.

Table 1 summarizes the default values to be considered in short and long-term work zones when assessing the capacity and speed of these areas.

Table 1. Default capacities and speed adjustments for work zones (freeways)
(Transportation Research Board, 2010)

Work Zone Type	Lanes Open	Capacity [pc/h/ln]	Speed Adjustment Factor	Capacity Adjustment Factor
None	All	2000	1,00	1,00
Short-term (1 day or less)	1	1600	0,80	0,80
	2	1600	0,80	0,80
	3	1600	0,80	0,80
Long-term (> 1 day)	1	1400	0,70	0,70
	2	1450	0,73	0,73
	3	1500	0,75	0,75

The approach also considers that lane width restriction adversely affects the capacity. For a lane width narrowed than 3,75m it should be applied an adjustment factor: 0,91 for lanes between 3,00 and 3,75m and 0,86 for lanes between 2.75 and 3.00m.
Due to the variety of work zone characteristics taking place in the highway and street system, the treatment of their impact on traffic operating conditions are not as systematic as in the case of freeways. However, an active traffic and demand management (ATDM) approach can be applied in these cases. ATDM is the dynamic management, control, and influence of travel demand, traffic demand, and traffic flow of transportation facilities (Transportation Research Board, 2010). Through the use of tools and assets, traffic flow is managed and traveled behavior is influenced in real time to achieve operational objectives, such as preventing or delaying breakdown conditions, improving safety or maximizing the system efficiency.
A work zone maintenance traffic plan may apply ATDM strategies tailored to these specific situations. Among typical ATDM strategies that can be applied in work zones it can be pointed:

- Traveler information strategies (TIS), to enable drivers to make a better-informed choice concerning travel routes and times.
- Managing-lane strategies, including the use of hard shoulders, in order to ensure an efficient use of available facility capacity.
- Speed harmonization strategies, such as variable speed limits, to improve safety and facility operation.

Solutions to help achieving the appropriate speed on different road types and roadworks have been addressed in Europe by the ASAP project - Appropriate Speed saves All People (FEHRL, 2016) (Vadeby, et al., 2016), and in the USA by the NCHRP 20-05/Topic 45-06: Active and Passive Speed Management Methods in Work Zones:

Technology and Procedures (Chitturi, 2013), and can be consulted in several available documents and web pages, as the cited ones.

Impact on safety

The research of Ullman et al. (2006) and Meng et al. (2010) shows that the probability of occurrence of serious crashes at road works zones is higher than outside these areas. However, the information in general available on this subject is still scarce.

European data used in the FORMAT project (2005), which counted with the participation of 20 organizations of 14 European countries, including Portugal and the United States America, indicate that work zone accidents represent less than 2% of all road accidents (3 to 5% for freeway networks). Similar values (2-3%) were presented at the ARROWS project (1998).

The analysis of Portuguese road accident data for the period 2010 to 2012 showed that work zone crashes represent 2 to 3% of total road accidents. However, this information is recorded along with the crashes due to the presence of obstacles on the pavement and 20% to 40% of reports have no clear information on the occurrence or nonoccurrence of this type of accident. These findings pointed out to the possibility that the actual percentage exceed the values obtained.

A descriptive statistical analysis of the Portuguese data points to run-off-road (13%), angle (12%), rear-end (11%) and pedestrian (12%) as the principal crash types of work zones crashes in Portugal, while speeding and disregard for vertical road signs or traffic lights are the most predominant registered contributing factors for work zone crashes. These factors are also pointed out in the consulted bibliography (Pigman & Agent, 1988) (Garber & Zhao, 2002) (Bai & Li, 2006) (Lu, Wang, & Wang, 2008) (Li & Bai, 2009) (Trafikverket, 2011) (Perco & Sar, 2012). The analysis has also shown that the percentage of work zone crashes has decreased over the analysis period. This may be related to the decrease of investment in conservation, maintenance and rehabilitation of road infrastructure.

As the occurrence of work zone crashes is a binary variable (occurrence/nonoccurrence) and they are affected by various factors, binary logistic models were used to address the related variables and explain the impact of predictor variables on the occurrence of crashes - relationship between the probability of the occurrence of crashes and explanatory variables (Mannering & Bhat, 2014) (Yang, Ozbay, Ozturk, & Xie, 2015) (Lu, Wang, & Wang, 2008).

In this study, the Logistic procedure was adopted and binary logistic regressions were performed for the analysis of accident data related with the principal types of crashes. A summary of the predictor variables considered in the binary logistic regression analysis and their impacts on the probability of the occurrence of the 4 most common crash types identified are presented in Table 2. In the table, cells filled with the letter "P" (positive) indicates that the factor has a significant impact on the occurrence of work zone accident. When the letter "N" (negative) is present, the impact is likely to decrease the probability.

Table 2. Impact of Factors

	Work Zone Crash Type Model			
Factor	Run-of-road	Angle	Rear-End	Pedestrian
Urban area	N	-	N	P
Heavy vehicle involved	N	P	P	-
Before crash, at least one driver involved is running straightly	-	P	-	N
Before crash and for the prevailing conditions, at least one driver involved exceed speed	-	N	P	N
Unexpected obstacle on the road (for at least one driver involved)	-	N	N	N
Disregard for vertical road signs and/or traffic lights (for at least one driver involved)	N	P	N	-
Posted speed limit ≥90km/h	-	-	P	-
Under the influence of intersection	N	P	-	N
Straight geometric design (not curve)	-	-	-	-
Level geometric design (not grade)	N	-	P	-
Clean and dry pavement	-	-	-	P
The presence of daylight	N	-	-	-
Weather is clear	-	-	-	-

Note: "P" – positive impact; "N" – negative impact; "-" – no impact

Regarding the factor impact analysis of the predict models, the factors rural area, no heavy vehicle involvement, no influence of intersections, upgrade/downgrade geometric design and the absence of daylight, are more likely to increase the probability of run-of-road crashes. For angle crashes, the opportunity of crash occurrence raise with factors like heavy vehicle involvement, running straightly, disregard for vertical road signs /

traffic lights and under an intersection influence. The probability of occurrence of rear-end crashes increases when the factors rural area, heavy vehicle involvement, speeding, high speed limit and level geometric design are present. Finally, pedestrian crashes easily occur in urban work zones, conditions of clean and dry pavement and for no speeding or influence of intersections.

Impact on user costs

By reducing capacity, work zones often cause user costs to rise due to increases in travel time, vehicle operating costs, and possibly the number and severity of crashes (FHWA, 2002). The magnitude of the additional user costs due to work zones typically depends on the timing, duration, scope, and number of construction and rehabilitation work zones characterizing each project alternative.

The factors mentioned above that can lead to additional road user cost (RUC) in work zones have been identified in several models and manuals in use, like HDM-4, TXDOT and NJDOT (Bennett & Greenwood, 2004) (Daniels, Ellis, & Stockton, 1999) (NJDOT, 2001).

The decrease in operating speed lead to traffic delays, which increases the value of time (VOT), and the consequent additional fuel consumption associated to traffic congestion, increases the vehicle operating cost (VOC) values. The work zone additional accident costs are also consider in some approaches, like QUADRO (Department for Transport S. E., 2006), by comparing work zone accident rates with the ones regarding normal conditions, however, rates in work zones are not commonly available.

Still, the most significant influence on RUC values occurs due to changes in operating speeds. These changes and the consequent additional travel time (delay) and vehicle operating costs were incorporated into the road user cost model formulation proposed for Portuguese trunk road (Santos, Picado-Santos, & Cavaleiro, 2011) by the consideration of work zones length, duration of interventions and posted operating speeds. The refinements made to the initial model to consider the impact of work zones programmed in RUC calculations are presented in the equations (1) to (4) (Santos, Picado-Santos, & Cavaleiro, 2014).

$$\mathrm{RUC\ (WZ)} = (\mathrm{dCf} + \mathrm{dVOC}) \times \mathrm{L_{WZ}} \times \mathrm{D_{WZ}} \quad (1)$$

$$\mathrm{dCf} = \mathrm{AADT} \times \sum_{i=1}^{4} (0{,}2 \times \mathrm{Cf_i} \times \mathrm{p_i}) \quad \text{for} \quad \mathrm{s_{WZ_i}} \leq \frac{1}{3} \times \mathrm{s_i} \text{ and ER, EN} \quad (2)$$

$$\mathrm{dVOT} = \mathrm{AADT} \times \sum_{i=1}^{4} \left(\mathrm{VOT}_{WZ_i} \times \mathrm{pi}\right) - \mathrm{VOT} \quad (3)$$

$$\mathrm{VOT}_{WZ_i} = 1/s_{WZ_i} \times \sum_{m=1}^{2} \left(\mathrm{TC_m} \times \mathrm{OR_{i,m}}\right) \quad (4)$$

Where RUC (WZ) is the additional road-user cost in work zones [€/km]; dCf is the incremental increase in fuel cost owing to work zones [€/km/day]; dVOT is the incremental increase in the value of time owing to work zones [€/km/day]; L_{WZ} is the work zone length [km]; D_{WZ} is the work zone duration [days]; AADT is the annual average daily traffic [vehicle/day]; i is the vehicle class: i=1 for passenger car; i=2 for utility; i=3 for heavy truck; i=4 for heavy bus; Cf_i is the fuel cost for vehicle i [€/km]; p_i is the vehicle proportion for vehicle class i; s_{WZ_i} is the average operating speed in work zones sections for vehicle i [km/h]; s_i is the average operating speed for vehicle i [km/h]; ER and EN are the Portuguese regional and national roads with two lanes (one in each direction) and "medium" design standards; VOT_{WZi} is the value of time in work zone sections for vehicle i [€/km/vehicle] and m is the travel purpose: m=1 for travel in work time and m=2 for travel in non-work time.

The work zone average operating speed to be considered in the analysis it is assumed to be equal to the work zone speed limit. These posted speeds depends on the timing with restrictions (hours of the day and days of the week) and legal framework. The operating characteristics of the traffic affected and configuration of work zones are considered through the definition of lower average operating speeds by road class.

Additional RUC in work zones due to changes in fuel consumption were only considered for Portuguese National and Regional Roads with two lanes operating at lower speeds (up to 1/3 of the normal operating speed). In these cases an increase of 20% in the fuel consumption was considered. The choice of this additional consumption value is based on the Portuguese passenger car representative vehicle manufacturer information that points to urban fuel consumption values of 20-30% higher than the combined ones (used for the definition of average situation) and, for heavy trucks, the additional values of 30-40% commonly obtained in fuel consumption models simulations (empirical models: IRC (1993), COBA (2002); mechanical model: HDM-4 (2010)) (Bennett & Greenwood, 2004) (Department for Transport S. E., 2006).

When traffic diversions are needed, changes in operating costs and travel time should be considered in the same manner as described before.

The formulation proposed was tested in order to evaluate, for several work zones scenarios and Portuguese road classes, the influence of work zones in unit RUC values [€/km], by vehicle class (Teixeira, 2011). An analysis considering that the road works take place during the day and night period, with a typical Portuguese traffic distribution by vehicle class (80% for passenger car, 10% for utilities, 9% for heavy vehicle and 1%

for heavy bus) and a distribution of traffic day/night equal to 85/15%, led to additional costs of about 15% for highways and 25-30% for the remaining network.

The consideration of additional road accident costs due to the increased probability of crashes in works zones are more difficult to address, even for a simplified approach. Based in the analysis of Portuguese accident data, a simplified approach can be proposed in a network basis level.

The study, conducted on Portuguese road accident data for the 2010-2012 period, showed that work zone accidents account for 2.6% of all accidents. About 93% of the victims of work zone accidents are slight injuries, 5% are serious injuries and 2% are fatalities. This allocation is similar to those for total accidents. Still, the number of minor injuries in work zones represents 2.5% of total slight injuries, serious injuries 2.8% of all serious injuries and fatalities 2.2% of total fatalities.

Based on these findings it is possible to consider that there is an additional cost of accidents in work zones of approximately 2.5% (see Equation (5)).

$$\mathrm{dAC} = \mathrm{a}(\mathrm{AC_t})/100 \tag{5}$$

Where dAC is the additional accident costs due to work zones, a is the increase in the network accident costs due to work zones (%) and AC is the accident cost [€/km/day] determined for a network and related to the year or period preceding the year of analysis. The AC can be calculated according to Santos, et al. (2011).

Conclusions

The approach presented, equations 1 to 5, allows to identify and quantify the main impacts of road work zones in operating conditions, safety and user costs. For instance, it can be said that it can be expected an additional cost of about 2,5 % for accidents in a section of road with a work zone when compared to a similar one without works. In terms of global user costs, an application to a freeway with an AADT = 10600 vehicles, 1 km long work zone, a speed reduction to 2/3 of the posted limit (80 km/h), an additional accident cost of 2,5 %, PSI (Present Serviceability Index) equal to 2 and toll cost was tested, resulting in an additional cost of 12 % when compared to the average values of RUC (in €/km/day). However, the global user cost can vary significantly with the volume of traffic and the work zone speed limit.

It is believed by the authors that the proposed framework allows to better support strategies in order to minimize and manage the impacts, to meet the safety and mobility needs taking into account the existence of road work areas, namely: minimize delays, maintain or improve the safety of drivers and workers, complete the work within the shortest time possible, and ensure access at the lowest possible user cost.

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