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Effects of stationary work zones on motorway crashes

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ABSTRACT

The empirical Bayes (EB) before-and-after method was applied in this study in order to evaluate the change in the expected crash frequencies associated with the installation of work zones on motorways. A dataset of 15,570 stationary work zones including crash data, road segment data and traffic data was analyzed in order to estimate crash modification factors (CMFs) associated with different layout configurations of work zones. The findings of this research indicated a general increase in crash frequencies due to the installation of work zones. Furthermore the analysis has shown that all layout configurations that involve a crossover are very critical for safety: the highest CMFs are observed for the configurations with only a partial diversion of traffic to the opposite carriageway (with part of the traffic remaining in the ordinary flow direction and part travelling in the opposite carriageway).

1. Introduction

Work zones are critical nodes of the road network in terms of safety as they require complex decisions to users and result in several points of conflict between the vehicles' paths. An appropriate work zone design and planning is a major priority to increase safety both for workers and motorists who drive through the complex array of signs, barrels and lane changes.

A proper estimation of work zone safety is required to evaluate the maintenance social costs when performing a whole life cost comparison of different possible design and maintenance strategies (e.g. in Pavement Management Systems).

Statistics from the U.S. (FHWA, 2016) recorded 669 fatalities related to work zone crashes in 2014, which was 2% of the total number of fatalities. Out of a total of 87,606 crashes recorded within work zones in 2010 (1.6% of the total number of roadway accidents) only 0.6% led to fatalities, whereas 30% were injury crashes and 69% were property damage only (PDO) crashes. During the years 2003–2012, at least 2 435 injury crashes occurred at various types of roadwork in Sweden (Liljegren, 2014). Of the 2 435 accidents, 42 were fatal accidents, 520 were accidents with serious injuries, and the rest were accidents with minor injuries. 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.

Very few studies exist aimed at quantifying the safety impact of roadwork activities. In accident analysis crash modification factors (CMFs) are used extensively to measure the ratio of crash reduction expected after the implementation of a countermeasure or to evaluate the safety impact of a specific condition of a given site. A wide body of research has focused on developing CMFs for different traffic and highway engineering improvements. However research concerning the estimation of CMFs related to roadwork has still some shortcomings.

This is confirmed by the survey recently conducted by Yannis et al. (2014) as a contribution to the PRACT project, a European project aimed at developing an accident prediction model structure for motorways and higher ranked rural roads (PRACT, 2015). A questionnaire, aimed at gathering a summary of experience on road safety measures and CMFs, was designed and dispatched to several National Road Administrations (NRAs) in Europe and worldwide. The survey results have shown great interest in providing reliable CMFs for work zones with the 86% of respondents indicating that there is a "high need" for CMFs associated with the installation of work zones.

Observational before-after studies are the most common methods for evaluating safety effectiveness and estimating CMFs for specific roadway treatments. The naïve before-after study, the before–after study with yoked comparison, the before-after study with comparison group and the Empirical Bayes (EB) before-after study are the four most common approaches used to evaluate

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the effects of a safety treatment (Persaud and Lyon, 2007; Persaud et al., 2010; Park et al., 2010).

This paper aims at investigating and comparing the impact of different work zones layout configurations (such as closure of a lane, crossovers, closure of the carriageway) on the expected crash frequency through the use of the EB before-after method.

The study used the following data:

- the work zone layout;
- start and end dates of roadworks;
- location and length of the work zones;
- number of crashes occurred during the pre-work zone and work zone periods;
- the annual average daily traffic (AADT);
- the geometric characteristics for each road segment.

All the data were provided by ASPI, the largest concessionaire for the construction and management of motorways in Italy.

2. Background

Crash frequency is usually used as a safety evaluation measure for work zones and is defined as the total number of crashes occurring at a specific roadway segment, facility, or network per unit of length and time.

Over the past 40 years, many researchers have examined the impact of work zones on roadway safety in terms of crash frequency. Several studies show that work zones have an increasing effect on crash frequencies when compared to "pre-work zone" conditions (Juergens, 1972; Graham et al., 1977; Liste et al., 1976; Nemeth and Migletz, 1978; Rouphail et al., 1988; Hall and Lorenz, 1989; Pal and Sinha, 1996; Khattak and Council, 2002; Srinivasan et al., 2011; Ozturk et al., 2014).

The study conducted by Khattak and Council (2002) showed that the total crash rate in the during-work zone period was 21.5% higher than the pre-work zone period, whereas the increase in non-injury and injury crash rates was 23.8% and 17.3%, respectively. Also Pal and Sinha (1996) found that crash rates in work zones in Indiana were significantly higher than those in "non-work zones" conditions. Furthermore, the outcomes of their research indicated that the average severe crash rate in work zones with a crossover between the two carriageways was generally higher than for partial lane closures even though this difference was not statistically significant.

The study conducted by the University of Florence (Saleh et al., 2013) as a contribution to the ASAP project, a European project addressed to the issues of speed management in work zones (ASAP, 2015), showed that the overall expected crash frequency, during the time when a work zone is installed on a motorway segment, is about 32% greater than the crash frequency on the same motorway segments in the "pre-work zone" period. The results also confirmed that crossover was the most critical layout for safety. However, the statistical analysis was conducted with the naïve before-and-after method in which the change in accident counts between the before and the after conditions is attributed exclusively to the work zone presence and the temporal trends that could change from the before to the after period are not taken into account.

Despite most studies agree that work zone presence increases the crash frequency, a recent review of the state of the art conducted by Yang et al. (2015) showed that the 48% of previous studies on work zone crashes indicate no clear evidence of the increase in crash severity during work zone conditions. This is also confirmed by the research conducted by Ha and Nemeth (1995) at nine work zones in Ohio which found that work zone crashes were slightly less severe than crashes in "non-work zones" locations.

Researchers applied different methodologies to address problems related to work zone safety analysis.

The Highway Safety Manual (HSM) synthesized a previous research (Khattak and Council, 2002) in order to provide quantitative evaluation of work zone safety (AASHTO, 2010). The HSM in Section 16.4.2 provides CMFs for all crash severities as a function of the duration and the length of work zones. The CMF related to the work zone duration is given by

$$CMF_{d,all} = 1 + (\%\ increase\ in\ duration \cdot 1.11)/100 \tag{1}$$

The CMF related to the work zone length is given by

$$CMF_{l,all} = 1 + (\%increase\ in\ length \cdot 0.67)/100 \tag{2}$$

The base condition of the CMFs (CMF = 1) is a work zone duration of 16 days and a work zone length of 0.84 km. The study conducted by Khattak and Council considered by the HSM investigated crash rates in the "pre-work zone" and "during-work zone" periods by using a dataset of California freeway work zones that included crash data and work zone data during a 2-year period (1992–1993). They considered work zone durations from 16 to 714 days, work zone lengths from 0.80 to 19.63 km and freeway AADT from 4000 to 237,000 veh/days.

In order to account for the combined effect of work zone length and durations the two CMFs should be multiplied as follows:

$$CMF_{total} = CMF_{l,all} \cdot CMF_{d,all} \tag{3}$$

This method takes into account only the combined effect of an increase in length and duration as compared to the base condition. Therefore this CMF cannot be used to estimate the effect of installing a work zone as compared to the situation without the work zone.

Khattak and Council (2002) developed a negative binomial model for crash modelling by using the AADT, work zone length and work zone duration. Separate models were developed for both injury and non-injury crashes in the "pre-work zone" and "during work zone" periods.

In the study conducted by Pal and Sinha (1996) the before and after statistic procedure suggested by Griffin (1982) was used to determine the effects of work zone presence in increasing the accident frequencies. Poisson and negative binomial regression models were developed to predict the number of crashes in work zones. The variables in the models included duration of the project, traffic volumes and the interaction between the variables. The studies mentioned above applied different methodologies ranging from observational naïve before-and-after comparison methods to the development of full work zones regression crash models (Safety Performance Functions) in order to assess the expected crashes in the work zones.

In the naïve before-and-after method, crash counts in the before period are considered equivalent to the expected crash counts if the safety treatment had not been implemented. The change in crash counts between the before and the after conditions is considered the treatment effect. This approach ignores the fact that work zone placement is not the only factor that might cause changes between the before and the after period.

The EB approach (Hauer, 1997) can be applied to account for the external factors that can affect a change in crash frequencies considering not only the regression-to-the-mean (RTM) effects, but also traffic volume changes and time trends in crash occurrence due to changes over time in factors such as weather, crash reporting practices and driving habits.