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Estimating safety performance trends over time for treatments at intersections in Florida

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ABSTRACT

Researchers have put great efforts in quantifying Crash Modification Factors (CMFs) for diversified treatment types. In the Highway Safety Manual (HSM), CMFs have been identified to predict safety effectiveness of converting a stop-controlled to a signal-controlled intersection (signalization) and installing Red Light Running Cameras (RLCs). Previous studies showed that both signalization and adding RLCs reduced angle crashes but increased rear-end crashes. However, some studies showed that CMFs varied over time after the treatment was implemented. Thus, the objective of this study is to investigate trends of CMFs for the signalization and adding RLCs over time. CMFs for the two treatments were measured in each month and 90-day moving windows respectively. The ARMA time series model was applied to predict trends of CMFs over time based on monthly variations in CMFs. The results of the signalization show that the CMFs for rear-end crashes were lower at the early phase after the signalization but gradually increased from the 9th month. On the other hand, the CMFs for angle crashes were higher at the early phase after adding RLCs but decreased after the 9th month and then became stable. It was also found that the CMFs for total and fatal/injury crashes after adding RLCs in the first 18 months were significantly greater than the CMFs in the following 18 months. This indicates that there was a lag effect of the treatments on safety performance. The results of the ARMA model show that the model can better predict trends of the CMFs for the signalization and adding RLCs when the CMFs are calculated in 90-day moving windows compared to the CMFs calculated in each month. In particular, the ARMA model predicted a significant safety effect of the signalization on reducing angle and left-turn crashes in the long term. Thus, it is recommended that the safety effects of the treatment be assessed using the ARMA model based on trends of CMFs in the long term after the implementation of the treatment.

1. Introduction

Traffic demand has increased as population increased. The US population reached 313,914,040 in 2012 (National Population Estimates, 2012). Increased travel demand may have potential impact on roadway safety and the operational characteristics of roadways. Total crashes and injury crashes at intersections account for 40% and 44% of traffic crashes, respectively, on the US roadways in 2007 according to the Intersection Safety Issue Brief (FHWA, 2009a). In order to alleviate this threat, researchers have to improve the safety at intersections. For example, one popular treatment is to convert a stop-controlled intersection to a signal-controlled intersection as suggested in the Manual on Uniform Traffic Control Devices (MUTCD) (FHWA, 2009b). The warrants state that signals shall be considered if crash counts exceed the threshold (FHWA, 2009b). In addition to the signalization of stop-controlled intersections, installing red light running cameras (RLCs) has been considered as a countermeasure because they can reduce the number of red light runners (Retting et al., 1999a,b,b).

Traffic researchers and engineers have developed a quantitative measure for safety effectiveness of signalization in the form of the Crash Modification Factor (CMF). Based on CMFs from multiple studies, the Highway Safety Manual (HSM) Part D (AASHTO, 2010) provides CMFs which can be used to predict the expected number

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of crash reduction or increase after converting stop-controlled to signal-controlled intersections (defined as "the signalization") and installing RLCs.

There is potential lag of drivers' awareness of roadway treatments suggested by Sacchi et al. (2014). Thus, the objectives of this study are to analyze the variations in the CMFs for the signalization and adding RLCs over time and to predict the CMFs for the treatments using a time series model. This information would be helpful for traffic engineers to understand trends of safety performance of the treatments in the long term. This paper evaluates the effectiveness of the signalization in reducing rear-end and angle + left-turn crashes and the effectiveness of adding RLCs in reducing total and fatal + injury crashes.

To better reflect the short term variations in CMFs, CMFs are calculated using the observational before–after study with the comparison group method in each month and 90-day moving windows. Then we applied the ARMA time series model to predict trends of CMFs over time for each treatment.

2. Background

Two hundred and fifty feet from the intersection center point has been commonly designated as the boundary of the intersection-influence area (Mcgee and Eccles, 2003; Mcgee et al., 2003; Harwood et al., 2007; Lord et al., 2008; Wang et al., 2008). In particular, crashes at signal-controlled intersections are closely related to driver's violation of traffic signals. For instance, Hill and Lindly (2002) found that the violation rate was 3.2 per intersection per hour. Retting et al. (1999a) also found that an average violation rate was 3 per intersection per hour in Virginia. Brittany et al. (2004) found that 20% of the drivers failed to obey the traffic signal. In general, higher rates of driver violation of traffic signals will result in higher frequency of intersection-related crashes. For instance, 6396 people who failed to follow the traffic light were involved in fatal and injury (F + I) crashes in Florida in 2005 (Yan et al., 2005).

Thus, researchers have collected the crash data and developed CMFs in order to predict the potential crash reduction once treatments were implemented. The CMFs for intersection-related crashes have been developed in the HSM (AASHTO, 2010) and National Cooperative Highway Research Program (NCHRP) Crash Experience Warrant for Traffic Signals (Mcgee et al., 2003). According to the HSM (AASHTO, 2010), rear-end crashes are expected to increase whereas angle and left-turn crashes are expected to decrease after the signalization. Persaud et al. (2005) evaluated the safety effect of RLCs and concluded that RLCs decreased right-angle crashes and increased rear-end crashes. Erke (2009) also showed that RLC reduced angle crashes by 10% and increased rear-end crashes by 40% using meta-analysis. Similarly, Abdel-Aty et al. (2014) found that adding RLCs increased rear-end crashes by 17–41% and reduced angle and left-turn crashes by 13% to 26%. However, a research conducted by Florida Highway Patrol (FDOT, 2013) claimed that RLCs even reduced rear-end crashes based on the result provided by 73 Florida law enforcement agencies. Approximately sixty percent of the agencies reported reductions in total crashes, side impact crashes and rear-end crashes. This result is not consistent with previous research (Erke, 2009; Abdel-Aty et al., 2014) which found an increase in rear-end crashes. These opposite effects of RLCs on rear-end crashes are potentially due to a lag of driver's awareness of RLCs in the short term after RLCs were installed and the variation in safety effects of RLCs over time.

To account for the temporal variation in safety performance, time series models such as the ARMA model (Box et al., 2013) have been applied by traffic safety researchers. Liu and Chen (2004) applied the ARMA model and the Holt-Winter exponential smoothing (Winters, 1960) to forecast traffic fatalities in the United States. Quddus (2008) applied the integer-valued autoregressive (INAR) to forecast crashes in the UK and compared the model with the ARMA model. Brijs et al. (2008) also applied the INAR model along with weather information including temperature, sunshine hours, precipitation, air pressure and visibility. However, these studies focused on modeling crash counts but not estimating the CMF using the ARMA model.

3. Methodology

3.1. Before–after study with comparison group method

Comparison group before–after study estimates safety effects of the treatment not only using crash data for the treatment sites, but also crash data for the untreated sites which are chosen as comparison group. The method compensates for the external causal factors that could affect the change in the number of

Table 1
Descriptive statistics for treated sites and comparison sites.

Variable	Numbers of treated sites	Numbers of 30-day intervals*	Average crashes per 30 days	Standard deviation	Minimum # of crashes	Maximum # of crashes
Signalization						
Rear-end crash	32	28	6.4138	2.1132	2	10
Angle + left-turn crash	32	28	3.1034	1.3976	1	6
Adding RLCs						
KABCO crash	19	36	8.1667	4.0249	2	21
KABC crash	19	36	4.3889	2.7597	1	13

Variable	Numbers of comparison sites	Numbers of 30-day intervals*	Average crashes per 30 days	Standard deviation	Minimum # of crashes	Maximum # of crashes
Signalization						
Rear-end crash	190	28	3.7241	1.6881	1	8
Angle + left-turn crash	190	28	4.3103	2.1062	1	9
Adding RLCs						
KABCO crash	95	36	100.1111	17.9073	58	138
KABC crash	95	36	37.9167	9.53	23	64

*Time length after treatment was implemented in 30 days unit.