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Safety analysis of urban signalized intersections under mixed traffic

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ABSTRACT

Introduction: This study examined the crash causative factors of signalized intersections under mixed traffic using advanced statistical models. *Method:* Hierarchical Poisson regression and logistic regression models were developed to predict the crash frequency and severity of signalized intersection approaches. The prediction models helped to develop general safety countermeasures for signalized intersections. *Results:* The study shows that exclusive left turn lanes and countdown timers are beneficial for improving the safety of signalized intersections. Safety is also influenced by the presence of a surveillance camera, green time, median width, traffic volume, and proportion of two wheelers in the traffic stream. The factors that influence the severity of crashes were also identified in this study. *Practical application:* As a practical application, the safe values of deviation of green time provided from design green time, with varying traffic volume, is presented in this study. This is a useful tool for setting the appropriate green time for a signalized intersection approach with variations in the traffic volume.

1. Introduction

Urban road traffic crashes in the state of Kerala, India, increased by 37% from 2009 to 2012. Nearly 20% of these crashes occurred at intersections. Crashes at signalized intersections formed 24% of the total reported crashes at intersections, and 40% of traffic related serious injuries and fatalities. Signalized intersections are major black spots in an urban road network (Antonucci et al., 2004; Kennedy & Sexton, 2009). A better understanding of the crash causative factors aids to develop more targeted countermeasures for improving the safety of signalized intersections (Tay & Rifaat, 2007). Very few studies in India examined the factors that increase the frequency and severity of crashes at signalized intersections.

Efficient signal phasing achieves equalization of traffic delays at different approaches, resolves conflicts between different traffic streams, provides flexibility to variations in traffic demand, and allows crossing streams for pedestrians (Wong, Sze, & Li, 2007). Safety issues arise when signal design violates design standards, or does not adapt to daily, seasonal, or yearly traffic variations. Inadequate geometric design, deficient road markings, and poor night visibility also depreciate the safety performance of signalized intersections.

In India, the selection of the optimum cycle time aims to minimize delay to the traffic passing through the intersection (IRC: 93-1985). This concept of signal design caters only to the needs of traffic demand and ignores the safety aspect. This results in unsafe conditions at signalized intersections and necessitates a shift from a capacity-oriented design to a safety conscious design.

The aim of the present study is to perform in-depth safety analysis of fixed-time signal operation under mixed traffic conditions with the following specific objectives:

- To identify the factors that raise safety issues at urban signal controlled intersections.
- To develop statistical models for crash frequency and severity prediction, considering the hierarchical nature of crash data.
- To evolve safety conscious guidelines for operation of signalized intersections.

This study is a stepping-stone in an initiative to upgrade the current Indian design standards for signal control design by incorporating safety into the design process.

2. Background

Factors that influence traffic safety of signalized intersections are control measures, geometric, traffic, driver, vehicle, and environmental factors (Bauer & Harwood, 2000; Chin & Quddus, 2003; Kumara & Chin, 2003; Tay & Rifaat, 2007; Vogt, 1999; Yan, Radwan, & Abdel-Aty, 2005). Research shows that increase in traffic volume, speed limit, percentage of truck traffic, and right-turning vehicles increases crashes at signalized intersections. An increase in the approach lane width and presence of left turn lane shows inconsistent relationship with crashes across various studies. India follows left hand traffic system and the left turn lane in Indian context is equivalent to the right turn lane in other countries that follow a right hand system. Wider approach median width, absence of left turn channelization, and acceleration section on left and right turn lanes have negative safety effects. The effect of

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multiple signal phases on safety shows inconsistent results and pretime signal control has reduced safety compared to adaptive control. Variables like the presence of surveillance cameras, aged drivers, and male drivers increase the chances of crash occurrence. The injury risk is also attributed to the type of vehicle used by the driver accused of the traffic offense. Injury risk increases in crashes that involve heavy vehicles, mainly trucks and buses due to the stronger force of impact during collision (Wong et al., 2007). Miaou (1994) and Wang, Ieda, and Mannering (2003) suggest that traffic flow data, categorized by approach and traffic lanes, is a more precise measure of the influence of traffic intensity on crash occurrence. The role of traffic signal operations like left and right turn phases, cycle duration, actuated control, and advanced warning flashers on intersection safety was also explored (NCHRP, 2009).

Researchers have modeled crash severity at signalized intersections based on traffic, roadway, driver, vehicle characteristics, and environmental conditions at the time of the crash (Abdel-Aty & Keller, 2005; Huang, Chin, & Haque, 2008; Jianming & Kockelman, 2004; Persaud & Nguyen, 1998; Rifaat & Chin, 2005). Factors like increased vehicle speed, reduced size of victim vehicle, female drivers, and driving without a seat belt increase the crash severity. Drivers at fault are less likely to experience high severity and crashes involving pedestrians show conflicting results. Some studies found that side impacts cause more severe crashes while others found that turning crashes are more severe. The presence of a divided minor roadway and increased speed limits on minor roads reduce crash severity.

Crash frequency modeling of signalized intersections adopts regression techniques like multiple logistic regression (Yan et al., 2005), log linear regression (Bauer & Harwood, 2000; Greibe, 2003), negative binomial regression (Vogt, 1999; Wong et al., 2007) and zero inflated negative binomial regression (Kumara & Chin, 2003). Crash severity is modeled using ordered probit (Jianming & Kockelman, 2004; Tay & Rifaat, 2007) and logistic models (Tay et al., 2008; Rifaat & Chin, 2005). Other modeling techniques include aggregate and disaggregate approaches (Persaud & Nguyen, 1998) and tree based regression (Abdel-Aty & Keller, 2005; Kashani & Mohaymany, 2011). The generalized linear models suffer from the common underlying limitation that each observation, being a crash or crash severity, corresponds to an individual situation. Hence, the residuals from the model exhibit independence. Multilevel data structure exists in crash data because of the data collection and grouping process, which defy the independence assumption (Huang et al., 2008). For correlated data within groups, models that do not appropriately consider the hierarchical data structure might yield inaccurate or biased parameter estimates (Jones & Jorgensen, 2003). Recently, the hierarchical modeling technique has gained an increasing amount of attention in crash frequency and severity modeling owing to the inherent hierarchical structure of crash data (Huang et al., 2008; Xie, Wang, Huang, & Chen, 2013). Lenguerrand, Martin, and Laumon (2006) state that road crash data have a hierarchical data structure with three levels: vehicle, crash, and occupant level.

Signal design in India adopts the earliest British practice in selecting the optimum cycle time based on the consideration that the traffic passing through the intersection suffers minimum delay. Webster's equation for optimal minimum delay cycle length assumes that the different green times of the phases are in the ratio of their respective flow values (IRC 93, 1985). Eq. (1) gives the equation for optimum cycle time calculation used in India.

$$C_o = (1.5 * L + 5)/(1\text{-}Y) \quad (1)$$

where C_o is the optimum cycle time; L is the total lost time for all phases; and Y is the sum of maximum flow to saturation flow ratio for all phases. The guidelines for design and installation of road traffic signals in India suggest that three cycles with different intervals, to cater to peak morning and evening and off peak traffic conditions, are required during the day. Since traffic flows and patterns change, it is necessary to regularly update the data and re-evaluate the signal design.

Crash prediction models assist researchers in exploring the crash causative factors at intersections and suggest general countermeasures. Very limited studies have probed the practical applications of these models at an advanced level. Here, the models are applied to understand the safety effect of deviance of green time provided from design value, with varying traffic flow. A study of this kind is not done in India, where development of road safety tools is in the very early stage. This handicaps the road authorities in developing road safety plans.

3. Site inventory and data collection

Signalized intersections were selected from three major urban agglomerates, namely, Trivandrum, Ernakulam, and Kozhikode, in the state of Kerala, India. Trivandrum is the capital of the state of Kerala. It is the largest and most populous city in Kerala. It is the political nerve center of Kerala and the major academic hub. Ernakulam is the highest revenue-yielding district in the state and is called the commercial capital of the state of Kerala. Ernakulam City has the highest road length and vehicle ownership rate among the cities in Kerala. Kozhikode is the third largest city in Kerala and the second largest urban agglomeration in Kerala. It has the lowest road length and vehicle ownership rate compared to the other two cities.

The intra-city public transport in the cities is dominated by the state-owned Kerala State Road Transport Corporation (KSRTC) buses. There are also bus services operated by private operators that provide access within city limits and beyond. City buses, taxis, and auto rickshaws form the means of public transportation within the cities. Motorcycles and cars are the favored means of personal transportation.

Traffic, geometric, and signal operation data of 110 approach legs from 32 intersections form the database for this study. These intersections are located in commercialized areas, or near major education or government institutions. There are no exclusive right turn lanes and exclusive left turn lanes with channelization are present at the majority of the approaches. Left turns are free at all times of the signal phase. It is pertinent to note that, in India, drivers drive on the left hand side of the road. At the signalized intersections, right turning vehicles filter across straight-through traffic streams.

All the signalized intersections have pre-determined fixed time controller settings, with no exclusive pedestrian phase. Most of the traffic phases have an amber period of 3 s, with no all-red phase. All major approach roads at these intersections experience very high traffic volume during the peak hours and queuing is common. There is no signal coordination or area traffic control executed in any region. The controller settings are not changed for seasonal or yearly traffic volume fluctuations in a long time. The green time is allocated according to the proportion of traffic flow. Almost all controller settings are set to a cycle time of 120 s. Otherwise, the signal installations are maintained in good condition. An intersection with precise signal phasing and controller settings requires no manual control by the traffic police. Almost all major intersections in Kerala have more than one police personnel to control the traffic. Increase in vehicular traffic, inadequate signal and intersection geometric design, weak compliance by users, and weak enforcement practices have led to an increase in the number of traffic casualties at urban signalized intersections in Kerala.

The data collected for the present study comprises road traffic crash data, signal inventory data, and volume count. Crash data of 3 years from 2009 to 2012 were collected from the database maintained by the city traffic police stations in the respective cities. Detailed information regarding the severity, type of collision, and exact location was taken from the First Information Report (FIR). Intersection inventory data were collected by direct observation and include geometric data, signal controller settings, and roadside information. The classified directional volume count was taken during the morning for 3 h