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# Crash risk analysis of different designs of toll plazas

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ABSTRACT

The Expressways (toll roads) offer a high level of service, and the Global Electronic Toll Collection market has exceeded the expectation. However, finding optimal designs for toll plazas is an issue with world-wide relevance, and this study makes a significant contribution towards this end. The main goal of this study is to examine for the first time the traffic safety impact of using different designs of the Hybrid Toll Plaza (HTP). In addition to that, this study helps understand the relationship between the crash frequency and several important crash-related factors and circumstances of these facilities. Crash data from a seven-year period was investigated, and a hundred mainline toll plazas in Florida were evaluated. The results of this study proved that there is a significant difference between the different designs of the HTP. And there is an indication that the majority of crashes occurred at diverge-and-merge areas before and after the plaza. Moreover, the results indicated significant relationships between the crash frequency and toll plaza types, annual average daily traffic, and driver-age. This study has also proved that the HTP and the All-Electronic Toll Collection (AETC) were associated with less number of crashes than the Traditional Toll Plazas by 44.7 and 72.6 percent, respectively. Also, one of the findings with interesting safety implications is the interaction between design type and percentage of prepaid transponder vs. manual payment users regarding crash rate. Overall, for those agencies who cannot adopt the AETC system, improving traffic safety at toll plazas should take a priority.

## 1. Introduction

The use of toll roads has risen dramatically in many countries around the world; and The Global Electronic Toll Collection market is valued at 5.42 billion U.S Dollar in 2014 and it is expected to reach 10.57 to 15.62 billion by 2022 growing at a CAGR of 9.16 to 12.71percent, (WISE GUY, 2017; MRR, 2017). In fact, the factors such as reduction in traffic congestion, low travel time, cashless travel facility and free flow of traffic are driving the Electronic Toll Collection (ETC) market growth (AB Newswire, 2017).

In the United States, there are many tolled road facilities; these facilities vary in type, size, ownership, and tolling systems deployed. Some of these facilities are private along with those owned and operated by various public agencies around the States (Yang et al., 2014). And even though toll roads offer high mobility benefits, traditional toll facilities may pose high traffic safety risk. Moreover, only a limited number of studies have explored the factors that affect safety at toll plazas.

The Transport Department of the Hong Kong SAR government conducted a trial traffic guidance scheme at the toll plaza of a busy road tunnel to improve traffic flow and traffic safety at this facility. A study by Wong et al. (2006) conducted an observational before-and-after study to assess the effects of the scheme. The results indicate that the trial scheme provided good guidance to drivers. Traffic safety was improved, and the travel time of auto-toll traffic improved in certain periods. Another study by Prasetijo et al. (2016) investigated the accidents at the toll plaza gates due to impacts of the vehicles with concrete crash barriers with results in damage and fatalities. The study conducted a simulation test for crash barrier Tensile Wire Fracture toughness system. The results show that the material for a new alternative crash barrier is likely to reduce the rate of death due to accident and damage with regards to road furniture and vehicles.

Valdés et al. (2017) evaluated the effectiveness of different electronic toll collection lane types, and how signage and queues affect safety and driver behavior and operations in toll plazas using driving simulator. The results showed that overhead signage configuration associated with the corresponding speed limits per lane was found to be significant in reducing the acceleration noise, thus reducing the potential for lane change related crash patterns. Also, female drivers tend to have a faster deceleration rate than male drivers in the toll booth approach zone. Moreover, no significant difference between genders on average running speed was found in basic tollway segment at the

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beginning of the experiment.

Saad et al. (2017) explored some of the factors that affect driving behavior and safety at toll plaza. This study assessed driving behavior using a driving simulator. They found that drivers experiencing the open road tolling (ORT) have safer driving behavior than those who use the tollbooth. Van Dijk et al. (1999) studied toll plaza in twofold: to configure the types of toll booths with multiple payment functionalities (cash, credit cards, and electronic payment); and to determine the number of toll booths for each type. The model was also used to validate the spacing, safety, and accessibility of the toll plaza. A hybrid approach of simulation and queueing theory were used in this study. The study showed that fewer toll booths were needed when different payment systems were separated, as a combination of different payment systems at one toll booth would substantially enlarge the variability of service times. This variability appeared to dominate the 'inefficiency' of separate toll booths which may seem counterintuitive. Consequently, the initial design had to be completely redesigned. Overall, none of these studies evaluate or simulate the impacts of using different designs of the toll plazas on traffic safety.

The literature also showed that different toll collection systems have been adopted by different toll agencies around the world with no uniform standard (Mohamed et al., 2000; Schaufler, 1997). The most common toll collection systems can be summarized as follows:

Traditional Toll Plaza (TTP); this design requires vehicles to rapidly decelerate, navigate through different fare transaction options, and then accelerate and merge with traffic (Miami-Dade Expressway, 2017; McDonald and Stammer, 2001; Abuzwidah and Abdel-Aty, 2015). These confusing maneuvers constitute safety challenges and form high risk locations on toll roads.

Hybrid Toll Plaza (HTP); this system retrofits existing tollbooths with express open Electronic Toll Collection (ETC) lanes. This design is allowing more than 81 percent of the vehicles in Florida to travel at full speeds using electronic transponders or license plate recognition technology in an open road environment with fewer diverge and merge maneuvers before and after the toll plaza. The HTP design combines either express Open Road Tolling (ORT) lanes on the mainline and separate traditional toll collection to the side, or traditional toll collection on the mainline and separate ORT lanes to the side (FTE, 2017). However, the HTP is widely deployed by many toll authorities such as in Florida, Illinois, New Jersey, and many other states.

All-Electronic Toll Gantry or All-Electronic Toll Collection (AETC); this system is completely barrier-free that replaces all tollbooths with regular express ETC lanes to change the toll plaza to be similar to regular segments. The AETC system allows driving straight through an open road without needing to change lanes, stop the vehicle, or even slow down to pay a toll. The payment will be done automatically, instantly and accurately by using the automatic toll collection transponder known as prepaid transponder (FTE, 2017).

Past studies and the current data have indicated that certain locations at the TTP and HTP are more likely to experience traffic crashes than the regular segments on the expressway. In April 2006 in Washington, D.C., investigators for the U.S. National Traffic Safety Board (NTSB) revealed that the most dangerous locations on the highways are toll plazas. In the same year, the NTSB reported that 49 percent of all crashes on expressways in Illinois occurred at toll plazas, and three times as many people died in them as in crashes on the rest of the same roadways. Also, 30 percent of all crashes on the Pennsylvania Turnpike happened at toll plazas and 38 percent of all collisions on New Jersey toll highways are toll plaza incidents (NTSB, 2017). An older study (Mohamed et al., 2000) found that about 32 percent of the total crashes that occurred on the Orlando expressway system were located at the Traditional Toll Plazas.

However, there are some obstacles to the use of the AETC systems in many countries around the world, and that because these systems require good arrangements between the tolling agencies and the department of motor vehicles, as well as the law enforcement and the regulations. These regulations and arrangements are needed to identify and bill drivers who do not have the prepaid transponder.

Although the use of the HTP and AETC systems has demonstrated measured improvements in traffic operations and environmental issues, the question is: What if we cannot apply the AETC? What are the alternative solutions? The answer was either adopting the HTP design or improving the current situations of the TTPs and it was proved that some simple and quick treatments could improve safety at TTP (Sze et al., 2008).

For example, Wong et al. (2006) evaluated the effects of a traffic guidance scheme for auto-toll lanes on traffic safety at TTP and they found that the overall lane-changing rate decreased significantly by 23 percent and the pooled conflict count decreased sharply by 44 percent, also the crash count decreased sharply by 38 percent. A better option however is to apply the HTP design and that also has some safety issues and there is a lack of research that compares and evaluates the different designs of the HTP, especially nowadays many agencies are adopting the HTP design without a uniform design standard.

Overall, to the best of our knowledge there were no studies evaluated the safety impacts of using different design of Hybrid Toll plazas (Fig. 1). Therefore, the main goals are the following:

1. Cover the urgent need of assessing the traffic safety impacts of using different designs of the HTP. It is worth mention that many agencies want to adopt Design 2 (Fig. 1) and that because it just requires adding separate ORT lanes to the side without touching the existing main-line toll plazas.
2. Investigate the relationship between crash frequency and the crash related variables such as geometric characteristics, toll plaza types, traffic volumes, and driver-age.

## 2. Methodology

### 2.1. Safety Performance Functions (SPFs)

Data from the reference group are used to estimate a safety performance function (SPF) that relates crash frequency of the sites to their traffic and geometrical characteristics. Generally, a safety performance function (SPF) is a crash prediction model, which relates the frequency of crashes to traffic (e.g., annual average daily traffic) and the roadway characteristics (e.g., number of lanes, width of lanes, width of shoulder, etc.). There are two main types of SPFs in the literature: (1) full SPFs and (2) simple SPFs. Full SPF is a mathematical relationship that relates both traffic parameters and geometric parameters as explanatory variables, whereas simple SPF includes annual average daily traffic (AADT) as the sole explanatory variable in predicting crash frequency on a roadway entity. It is worth mentioning that the calibrated Crash Modification Factors in the Highway Safety Manual are based only on the simple 'SPF' (Abdel-Aty et al., 2014). Therefore, a series of SPFs were developed in the first part of this study using Negative Binomial Regression Models.

### 2.2. Negative binomial regression model

Crash data have a gamma-distributed mean for a population of systems, allowing the variance of the crash data to be more than its mean (Shen, 2007). Suppose that the count of crashes on a roadway section is Poisson distributed with a mean $\lambda$, which itself is a random variable and is gamma distributed, and then the distribution of frequency of crashes in a population of roadway sections follows a negative binomial probability distribution (Hauer, 1997). Count data is usually modeled using a Poisson distribution; the main characteristic of the Poisson distribution is that its mean is equal to its variance. Several studies found that a negative binomial distribution fits crash frequency data better (Brown et al., 2006) (Abdel-Aty and Radwan, 2000). The Negative Binomial (NB) is similar to a Poisson distribution, though its