International Journal of Engineering, Management, Humanities and Social Sciences Paradigms (IJEMHS)
Volume 30, Issue 02, Quarter 02 (April to June 2018)
An Indexed and Referred Journal with Impact Factor: 2.75
ISSN (online): 2347-601x
www.ijemhs.com

Design of Toll Plaza using a Coupled Multiple Queue-Multiple Server Queuing Model

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Publishing Date: June 16, 2018

Abstract

Toll plaza operation is a critical component of roadway operations throughout the country, as tools provide both revenue for expansions and opportunities for demand management. Electronic tolling has introduced a new form of driver decision making at toll plaza due to the additional payment. Describe the user convince marking at toll plaza due to the additional payment. Despite the user convince these facilities gives to consumers, this form of collection has not come without safety and operational concerns. Recommendation for future research include to examine traffic flow and safety impact at toll plaza under varying traffic condition and demand with open road tolling lanes strategies. Developing enhancements to vision to address parameters limitation associated with discrete choice modeling at toll plaza. Multi-server queuing analysis can be used to estimate average time and queue length at toll plaza and parking exit plazas giver arrival rates, number of services, and services rates. These queuing models approximate the performance of queuing system with multiple queues. To gain and understanding of how such a system will operate, a traffic simulation model that reflects the specified vehicle arrival and services rates to allow for a multiple channel arrivals was applied to several parking exit plaza concepts. After discussing the natural behavior of traffic and making a few reasonable assumptions to simplify traffic streams in a toll plaza, we break the travel process in a toll plaza into two stages: Toll collection and Margins. We apply queuing theory to each stage, modeling each stage as a queuing system. Having determined that an optimal toll plaza minimizes travel time, we derive a formula to calculate the average wasted time per driver in terms of number of incoming lanes, traffic flow and number of toll booths.

Keywords: *Queuing Model, Toll Plaza, Coupled.*

Introduction

Toll financing has been used throughout the history of civilization to make the building of long-distance roads possible. Toll roads in Asia were known to ancient Greek writers in antiquity. The first turnpikes in America were built in the 1790s and helped to open the Midwest to settlement. Beginning in the 1940s, America's first modern freeways were financed with tolls, paving the way to the Interstate system Americans now enjoy. Today developing nations such as China are building their own networks of superhighways, and they too are turning to the tollbooth to foot the bill. As the congestion and pollution from too many cars on the streets become an increasing concern in many cities, another benefit of tolling has revealed itself: Tolls are being used successfully in places such as Singapore and London not just to finance road construction, but to limit the flow of vehicles into the urban core, increasing transit usage and unclogging the crowded streets.

Despite its many advantages, there is one undeniable drawback to tolling that is the bane of drivers and road builders alike: When traffic is thick, cars back up in line to get to the tollbooths, and after paying their tolls, drivers lose time scrambling for position as the many lanes exiting the toll plaza merge together, returning the road to its original width. It's a real problem, as confirmed by the experience of transportation departments around the world. A study conducted at the New Jersey Institute of Technology estimates that a travel time savings of 2 minutes, or over 10 percent, could be affected by the removal of two toll plazas along a 14-mile section of the Garden State Parkway.

Modern toll facilities, such as Highway 407 near Toronto and the SR-91 Express Lanes in Orange County, California, require all payment to be made by means of electronic transponder, so that vehicles do not have to slow down in order to pay the toll. But on many older toll ways moving to all-electronic payment is not an option, while mounting congestion means that planners are faced with the problem of configuring their existing infrastructure to provide the best possible service. To get rid of long lines, common sense suggests that providing as many tollbooths as possible will minimize the toll payment delay, but more tollbooths mean more merging and hence more

congestion after the tolls are paid. In this paper we will investigate the question of choosing the right number of tollbooths to get an optimal balance between these two factors.

Conflict and Event Study Notes

The conflict and event study supplemented the field data collection the micro simulation model development. Utilizing practices from FHWA's observers guide to Traffic Conflict techniques, a review of safety and operations was conducted at the West Springfield I-90 toll plaza.

Conflicts vary depending on origination of vehicles competing for the same roadway space. For the purpose of this research, same direction conflicts were nearly exclusively studied. While opposing conflicts may occur, their risk at exit and entrance plazas in Massachusetts is mitigated by stanchions, cones, low speeds and center lane closures. Pedestrian conflicts from toll plaza employees do occur from time to time but authorities limit exposure to this risk through training.

Same direction conflicts in toll plazas are primarily related to lane-changing events. In these instances, the overtaken vehicle is in danger of rear ending or sideswiping the provoking vehicle. The result of conflict may lead to a secondary conflict where a following or nearby vehicle may have to decelerate, maneuver unevenly to avoid a collision. Secondary conflicts commonly appear as a more relaxed deceleration. While a secondary conflict may seem to trigger a tertiary conflict, no such term exists.

Table 1: Conflict and even register

Conflict and Even Register	
Abrupt stop	1 per hour
Evasive Maneuver	4 per hour
Car Honking	9 per hour
Swerving	1 per hour
Secondary braking	7 per hour

Crash Analyses

Crash analyses were performed on crashes occurring in the Commonwealth of Massachusetts from January 2010 through December 2012. All crash figures were linked geographically to toll plazas on the basis of proximity and contributing role in the collision. All toll plazas, mainline and entrance and exiting were considered for inclusion regardless of whether there was a transaction or just a "ticket" or digital "ticket" issued for interstate entrance. Traffic count data from MassDOT contained transactional toll records of exiting vehicles; therefore crash rates were based on the dataset of crashes exclusive of entering vehicles. All other plazas including mainline plazas, tunnels, and bridge facilities contained all toll crashes.

Results, Discussion and Recommendation

Conflict and Event Study

Crash histories provide engineers with trends in moderate to severe safety concerns in the form of collision reports. Other incidents may be occurring that due not lead to a crash but nonetheless may be jeopardizing the safe and efficient passage of vehicles through a toll plaza. The conflict and event study results addressed the objectives outlined in section 3.1.1. Honking and secondary braking were the most prevalent events triggered by other vehicles in the toll plaza environment. Lane changes and last second maneuvers may be the result of the late epiphany by drivers that they may be sitting in an inappropriate toll lane. Alternatively, these events may be the consequence of an aggressive driver in the pursuit of shedding 20 seconds off their commute to work. Configurations that minimize lane changes were considered in the static evaluation and micro simulation tasks based upon this feedback.

Crash Analyses

Aforementioned in Chapter 4 results, crash analyses were completed by single and double variables in an attempt to gain insight into toll plaza safety. Crash history analysis fulfilled objective 1 outline in Chapter 3. Reviewing toll plaza statistics led to the following considerations. The Weston exit 15 boundary plazas had the highest number of plaza crashes. While overall toll plaza crashes are a minimal portion of 200,000 crashes each year in the Commonwealth at less than 0.1 percent of all crashes some toll plazas have higher crash rates than the state wide urban interstate average. Nonetheless, investigation into the origin of these highway mishaps may prevent future injury and improve overall highway safety at these frequented highway junctures.

Crash Rate per Plaza

The Weston and Allston/Brighton plazas have crash rates 3 times higher than statewide averages. Furthermore, a total of seven plazas have higher crash rates than statewide crash averages for interstates. Concerning as these rates may seem, multi-variable trends may provide insight to what may be leading to these safety issues. Certainly, high travelled roads introduce higher probabilities of vehicle to vehicle interactions. Congestion on the other hand may have a secondary and unintentional safety benefit that lowers average speeds around plazas and ultimately decreases the severity and perhaps collision frequency.

Time of Day

Time of day analysis indicated a higher amount of crashes during the busiest times of the day. Results were not normalized for hourly traffic volume variations due to a lack of data availability for all plazas. The records do not suggest a higher number of crashes during late night due to free flow conditions and a driver's ability to travel at higher speeds as previously predicted.

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