Analysis and Behavioral Study of Traffic using VISSIM

[1]Abhishek Jindal, [2]Mr. Pradeep

Transportation Engineering
Sat Priya Institute of Engineering and Technology

***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. Estimation of queueing time and queue length at toll plazas and parking exit plazas using a multi-server queuing analysis allows you to determine average time and queue length. This model approximates the performance of multiple-queue queuing systems. To better understand how a system would work, a traffic simulation model was used to simulate several parking lot exit plaza designs that accounted for numerous channel arrivals. We've identified the natural behaviors of traffic, and we simplify these behaviors by applying a few plausible assumptions to traffic flows in toll plazas. After we've settled on these assumptions, we have divided the trip process at toll plazas into two stages: collection of tolls and margins. The notion of queuing is applied to each step of the process, which is modeled as a queuing system or VISSIM. Having discovered an ideal toll plaza, we work up a formula to find the average time lost per motorist due to the traffic flow, the number of toll booths, and the number of incoming lanes.**

***Keywords*: Toll Plaza, Electronic tolling, multiple-queue queuing systems, traffic condition, traffic simulation, VISSIM**

I. INTRODUCTION

Building long-distance roadways throughout history has required the use of toll funding. Ancient Greek poets knew about toll roads in Asia long before they were built. During the early decades of the 1800s, the first turnpikes were constructed throughout the Midwest and opened up the Great Plains for settlement. The first modern motorways in the U.S. were built by means of tolls, laying the groundwork for the interstate system Americans enjoy today. We've recently seen the rise of emerging countries like China, who are now constructing their own superhighways and asking drivers to pay tolls. Yet another advantage of tolling has emerged: Tolls are successfully being utilized in Singapore and London to fund roadway improvements, but they are also being utilized to restrict the number of automobiles in the urban center, leading to increased transit utilization and relieving the congested streets. In spite of all of its benefits, one major downside does remain: that is, tolls have a tendency to aggravate drivers and constructors alike. When traffic is backed up, vehicles start to move in a line to the tollbooths and when they pay their tolls, they find themselves blocking the flow of vehicles, thus creating a time loss as the numerous lanes exiting the toll plaza rejoin the flow of traffic, returning the road to its original width. According to transportation agencies throughout the globe, it's an issue. New Jersey Institute of Technology research claims that removing two toll plazas on a 14-mile stretch of the Garden State Parkway might save drivers on average over 10 percent of their travel time.

In contrast to traditional toll plazas, such as those on Highway 407 near Toronto and the SR-91 Express Lanes in Orange County, California, modern toll facilities, such as those on Highway 407 near Toronto and the SR-91 Express Lanes in Orange County, California, enforce all toll payments through electronic transponders, so that vehicles are not inconvenienced when making toll payments. While escalating congestion requires that designers take steps to better configure their current infrastructure, increasing toll traffic makes implementing electronic toll collection infeasible for older tollways. It's simple: provide as many tollbooths as possible, and customers will no longer have to wait in lengthy queues to pay their fees. We'll study how many tollbooths to choose in order to achieve an ideal balance between the two parameters: efficiency and convenience. To obtain a complete and accurate analysis of the problem, we must conduct a thorough qualitative study in which we identify the aspects of the problem we should focus on, which we should disregard, and what rules the system components are expected to follow. Furthermore, we must create a metric for highway performance. Once we know the traffic flow level, the number of tollbooths, and the number of initial lanes, we can apply some results from queuing theory to find a way to compute the performance level for a toll plaza given the amount of traffic, which will allow us to determine the number of tollbooths and the number of additional lanes. Simulation efforts have been concentrated on toll plazas for some time. An increasingly popular approach is event-discrete models in toll plaza modeling. These models do a great job representing the user-server process, but they do not capture all of the traffic-related behavior and interactions that occur on facilities. approaching the “most convenient lane” region and the exit, both of which are subject to weaving and specific right-of-way laws (priority rules). The perceived degree of service greatly depends on these traffic factors. In order to understand these problems, advanced simulation models that include a stochastic description of both the server-user interaction and the traffic operations have been created in the last several years.

This study uses VISSIM, a traffic simulation model, to evaluate and design the locations of parking facilities detailed in it. a microscopic, time-step and behavior-based simulation model that analyses the traffic operations for nearly any form of transportation method has been constructed using VISSIM highway Although the concept was not expressly designed for toll plazas, many of the features resemble toll plazas.

1.1 General Toll Plaza Operation and Configuration

By means of an introduction to the topic being proposed within this thesis, it is important to first have a basic understanding of general toll plaza operation and configuration. The general operation and configuration of a toll plaza is based upon basic elements that may differ across various plazas, including the following:

- Plaza type;
- Lane types;
- Electronic tolling technology hardware; and,
- Electronic tolling technology software.

1.2 Plaza Types

Since the 1960's a barrier toll plaza has made up the majority of interchange installations. As shown in Figure 1, these plazas are typically located on the freeway itself and require a fare in order to proceed on the highway. These tolls are typically flat fee (by vehicle/axle type) to continue on to the next segment of the highway. Some barrier toll systems allow free movement between some exits. In some cases, unrestricted access is implemented for intercity facilities where real estate is limited. Toll plazas are often located at the boundaries of urban areas and charge to enter the city from rural and suburban areas. The other type of toll facility, known as a ramp plaza, requires a toll to enter and exit. These tolls are most frequently distance based tolls, meaning the motorists receive a ticket upon entering and pay a toll upon exiting that is related to the distance traveled.

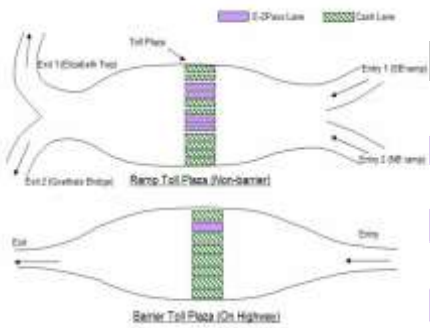

Figure 1: -Toll Plaza

Lane Types

There are five general types of toll plaza lanes in use today within the United States. The most basic lane type is the traditional cash lane where a toll attendant collects a fare physically in the form of currency. This method, while still used today, is a costly and time-consuming form of fare collection. In hopes of automating the collection process, automatic coin counting machines were developed to reduce personnel costs and increase throughput. The next advancement in toll collection came in the form of electronic toll collection with transponders. ETC tolling was originally referred to as automatic vehicle identification (AVI) because transponders have unique serial numbers that link to a patron's pre-paid account. The vast majority of ETC lanes are exclusive, meaning only transponder subscribers are allowed to utilize those lanes. A hybrid of 4 ETC and cash lanes are referred to as combination or mixed use. These manned booths help reduce complications such as the serious hazard of a motorist backing up during arrival at the collection station in the wrong lane. The final category of electronic collection lanes is termed express because they require minimal to no deceleration allowing fare transactions at high speeds. Express lanes are loosely defined as a segregated expressway for electronic toll users. Known more commonly as open road tolling, express lanes are the most transparent form of tolling as they do not require motorists to exit the highway or reduce speed. Often plazas with express lanes will also have dedicated lanes in the plaza for motorists who miss these separate lanes. Electronic tolling lanes have substantial fare processing capacity over manual lanes as seen in Table 1.

Table 1 Operational toll attributes

	Operational toll attributes		
Tolling Lane	Collection Method	Average lane speed (miles per hour)	Throughout (vehicle per hour)
Type Cash	Manual Attendant	Stop	300
Automatic	Manual Machine	Stop	500-600
Combination	Manual & Electronic	7	700
Dedicated	Electronic	15	1200-1500
Express	Electronic	55	1800-2200

1.3 Limitations of the Model

It has the most conservative findings since it depicts the worst-case situation. the lack of account for the behavior of customers who pick the shortest queue server, and of no queue "jumping," which is permitted in this model varies from what would be considered "normal" behavior at toll vehicle-selecting plazas where cars seek for the shortest-line route and 'jockeying' among different queues in certain instances, it is acceptable. the overall environmental impact In many countries, new highway construction is required to have an environmental impact analysis performed prior to the commencement of construction, and to include a design that minimizes environmental damage. In terms of its effect on the environment, the primary consequence of a highway is the pollution caused by car exhaust. In many localities, the impact of motorways on nearby animals and on the noise pollution they cause is of great concern. It doesn't seem practical to focus just on one of these variables while figuring out the best option for your trip. Even if you agree that the majority of the road's main users are those who use it for transportation, and their focus is on speeding up travel time, you can still think that this comment is foolish. So, if we include environmental aspects, we must maximize the two of them while taking into account trip time, meaning that we must do so in combination with a single utility function that depends on travel time and environmental aspects.

Until you take into consideration the variables of the environment, it does indeed seem to be an unsolvable task. The destruction of wildlife habitat is a side consequence of the construction of the highway. Most of the habitat loss happens due to the barrier effect of the road and the noise and pollution created by motorists on the road. As tollbooths aren't critical to the system, optimizing is difficult, and just pollution and noise are left. Nevertheless, there is a clear correlation between the amount of pollution and noise, and the number of motorists in the vicinity of the toll plaza at any given moment. Reducing the number of autos, together with the fact that there is no method to manage incoming traffic flow, necessitates traffic management at the toll plaza. All other things being equal, lowering travel time will reduce the environmental effect. Therefore, we have concluded that further consideration of environmental effect is unnecessary.

II. BACKGROUND

The toll plaza environment is in many regards one of more complex and demanding places to drive in terms of safety and motorist involvement. Vehicles approach at high speeds and decelerate at various speeds while merging and scanning for signage and toll lanes. In order to understand the intricacies of toll plaza operations, a review of current and past literature was compiled. Studies highlight driver decision making, signage, lighting give light to the vast amounts of sensory information and methods of payment. Simulation efforts with ETC equipped toll environments have revealed the theoretical performance and introduced behavior models to hopes to replicate and predict real world events. The following background is by no means an all-encompassing review electronic tolling safety and simulation but should provide a backdrop for the research proposed herein.

Contrastingly, a 2007 report of the New York State Thruway Authority crash records showed an increase in ETC related crashes as ETC penetration increased from 1992 to 1998. Crashes on an Orlando Florida expressway doubled after installing dedicated ETC lanes. The crash rates involving dedicated ETC lanes and/or ETC vehicles rose from 3.375 crashes per month to 7.5 crashes per month. At the same toll facility, rear-end crashes increased as a result of a adding a dedicated ETC lane. Not even a year later a second adjacent ETC lane was installed, and again rear-end crash frequency increased. Speed was the leading cause of conflict and the culprit in raised accident rates. Prior to toll plaza renovations speed variance was low, but after construction velocities noticeably escalated. These results provide strong support to the idea that decision making spurred by ETC lanes may spark conflicts at toll plazas that are leading to additional accident. Another model, TPSIM, built by Correa et al. (2004) was able to reproduce typical toll plaza operations with lane decision based on queue length (14). The deterministic toll plaza software SHAKER created by Florida Department of Transportation out puted most efficient plaza configurations by assigning approaching traffic to shortest queue lanes. TOLLSIM toll plaza model, developed by Wilbur Smith, now CDM Smith, estimates traffic characteristics such as delay and queues at a plaza. Few studies have developed toll plaza micro simulations with widely available traffic simulation programs (AIMSUN, VISSIM, Paramics, CORSIM). The model produced by Mudigonda et al. (2008) revolves around maximizing user utility based on three parameters for ramp plazas was programmed into an API by Nezamuddin. The model validated mainline plazas on Orlando Orange County Expressway Authority (OOCEA) toll facilities. The study found success in modeling field observations with correlating lane assignments on the order of 0.98.

III. DESCRIPTION OF MODEL

3.1 Simulation of Queuing Using Traffic Simulation Software

The models that are used in the various mathematical formulations include assumptions about the arrival and processing rate distributions and the kind of dispatching disciplines. As a result, these maps do not accurately represent the volume of traffic as you approach and go through them. leaving the toll booth for these restrictions, HNTB has created apps to solve these issues. Utilizing VISSIM, to include traffic simulation software into the toll plaza environment VISSIM is a simulator that is increasingly rising in popularity for traffic scenarios A transportation complex is developed both in the United States and abroad. the model consists of two major components the major components that are simultaneously used. Traffic model that depicts traffic flow signal control model in microscopically small steps, a fixed time-slice, and stochastic, the simulation is created (one second intervals). The simulation outcome is an online animation of traffic flow and many traffic operations measures that are put in place offline. To simulate the behavior of connections, links are not utilized in the simulator. Because VISSIM has no standard node-link structure, it is not classified as a structure. There are no nodes, hence the user has to make their own routes. Flexible enough to adjust traffic operations, such adjusting lane controls or route design involving complicated geometry on roads. The traffic flow model in VISSIM is based on two different models. longitudinal vehicle behavior is governed by the car-following model a rule-based system governs lateral motions in the lane-change model.

On general, in the road, automobiles maintain their position relative to one another by alternating back and forth between them. In a single lane, a quicker vehicle must decelerate if it comes to a stop behind a slower vehicle. Depending on the distance and how quickly the vehicle is traveling, the time connected with this response will vary. While driving on multi-lane roads, cars constantly compare their existing conditions. By changing lanes, you may go at (traveling speed) Otherwise, they investigate whether or not there are acceptable gaps on lanes next to each other If the car is available, it will automatically switch lanes and go forward.

3.2 Application of VISSIM to Toll Plazas

Though toll plazas are a popular use of VISSIM, which was intended for restricted access road and surface street networks, toll plazas are not the only use of VISSIM. Although the model has numerous features that support toll plaza development simulations, it does not cover all of the possible features. a minority of the For these specific purposes, the capabilities of the model are shown below.

Dynamic assignment of vehicle paths:

Macro programming language included inside the model allows the simulation user to interface with cars while running the simulation. This function is especially beneficial when using toll plazas since cars are only permitted to use the tollbooth that is currently active. Vehicle presence is detected by employing inroad detectors on the network. For each second of the simulation, the computer will determine which of the observed cars has the "most convenient" route and then checks the state of the detectors. In addition to tracking every car and those who have left the lot, the application also maintains track of all vehicles that are allocated to each service lane.

In addition, the service rate is used to determine a “perceived waiting time” for every vehicle that is allocated to a given lane. The simulation will evaluate the condition of the system and indicate which lane is the most convenient for the following car every second, and Vehicles now have the necessary information to identify their lane of travel.

Priority Rules: According to our discussion earlier, regulations of the road or distinct highway approach or departure circumstances apply in the plaza area. It is a lower-speeds environment, therefore most of the driving lanes are dedicated to laned traffic. In comparison to other times, changes occur and there is more awareness of drivers, resulting in more serious accidents. The practice of weaving is seen as quite natural. Coding priority rules that regulate may be included with the model. Each car will surrender to the car ahead of it. either a time gap or time difference as close as possible to all vehicles Great flexibility in this feature is enabled Incorporating vehicle interactions.

Service Time Distribution: Specifying either an empirical or a normal distribution of processing time is supported by this feature. This is particularly essential in scenarios where toll transaction time data are available, since in this case it is possible to conduct a more accurate simulation of processing performance. The service times do not need to be Poisson distributed unlike the models. Vehicle classes such as those using electronic toll collection, using precise change, or using cash at a toll plaza, and pay-on-foot might result in differing processing rates.

Speed Reduction Zones: Varying desired speed distribution is given by mode, for instance, for an individual travel lane, enabling for toll lanes to be simulated that enable cars to bypass toll plazas.

Driver Behavior: In order to customize how drivers, interact and behave in the plaza, numerous factors in the model may be modified. In real life, people tend to exhibit more aggressive or more cooperative conduct.

Administration of Evaluation

A secret email connection was used to provide the assessment results to coworkers, without publicly putting them elsewhere on the internet. During a 3-week collecting period, the published results were made accessible.
Captivate recorded user results to an XML file to a local server.

Analysis of Evaluation

Evaluation responses were compiled and results were aggregated through extraction of each individual XML file. Data was sorted by scenario number and demographic responses. Results provided feedback and configurations to pilot in the micro simulation model development in task 5.

Micro simulation with VISSIM

Task 5 was conceived to address research objective 3 as mentioned previously.
Tasks 2-4 led to improvements in the modeling of toll plazas based on lane arrangement, culminating in an effort to further enhance the overall safety and driver decision-making of toll plazas. To examine the operational characteristics of toll plazas, a micro-simulation VISSIM model was created. The feature of a toll plaza is absent from VISSIM, unfortunately. As part of the development stage, VISSIM configuration resources were put in place to emulate the traffic control operations of a toll plaza. The toll plaza was constructed in the micro simulation package in West Springfield. Toll plaza safety and performance were studied via the use of video. This data was utilized as an example toll plaza's VISSIM model input.
Parameters were calibrated to provide the same results as the observed behavior after development. To calibrate the model, we first used eye inspection to see how the model handled routine traffic operations. At a toll plaza, a little amount of weaving, queuing,

and other less predictable actions are to be anticipated. Gridlock or other irregularities in the model may be found through eye examination.

Toll Plaza Configurations Based on the January 2012 Configuration were Created into VISSIM. After calibration, another toll plaza configuration mirroring the configuration in January 2012 was built into VISSIM. To determine the validation model's efficacy, the observed field volumes' total throughput should be within ten percent of the model results. The innovative end product was capable of predicting traffic operability based of configuration and an origin destination study. A critical benefit of this model may be the ability to aid toll plazas managers in optimizing lane configuration.

Model Development& Base Data

In an effort to build a robust micro simulation model, good field data must provide the framework to erect a reasonable representation of realistic activity. Field data was collected during the year 2012. The available datasets are summarized in Table below. Unfortunately, both data sets were not recorded at the exact time of day, but were both recorded mid-week, off peak hours. Location of this particular toll plaza is not susceptible to large swings in destinations due to commuting.

Table2:- Field collection datasets

Date	Time	Hours collected	Location	Cameras	Toll plaza lane configuration	Weather
25 dec 2015	12pm	1.25	West string exit-2	2	Cash-EZpass-EZpass cash	33 degree overcost
15 jan 2016	11am	1	West string exit-2	1	Combination-cash-EZ pass-combination	34 degree overrate

IV. Data Reduction and Preparation

In order to prepare the data to serve as model inputs, our video data was reduced to usable inputs. Raw volumes and traffic class information were collected using a JAMAR Technologies count board with 15-minute increments as archived in Table 4. Car and heavy vehicle (single units, buses, tractor trailers) volumes were separated for vehicle classification. Origin and destination figures were required for dynamic assignment. While Massachusetts Turnpike exits may be found at both the north and south ends, they have two entries and two exits. There were two exits from the turnpike, one from each way. Interchanges were: 1) southbound I-91 to Route 5; and 2) northbound I-91 to Route 5. Figure 8 shows the 2-camera arrangement for collecting origin-destination information. The toll plaza on the overpass of Prospect was photographed from a camera located to the left of the toll plaza. Field data video image shows each vehicle tracked from their entry lane, through the toll plaza, and to their ultimate destination, using the data from cameras 1 and 2, as seen in Figure 9 Along with the information of origin and destination, payment method, lane choice, and number of lane moves were logged. This procedure revealed the toll payment methods that clients used as well as their direction of travel: Eastbound, Westbound, or a combination of the two. This input was transaction time which was recorded inside the toll plaza borders. As a measure of the time, it takes to complete a transaction, transaction time did not account for time spent in wait or travel time to an exit point. Commencement time was measured as the time differential between the moment the front of the vehicle passed the physical toll booth (the point of passage) and the moment the rear bumper of the vehicle reached the end of the toll booth and made it through the traffic signal with a green ball displayed (completion time).

Vehicle Classifications & Traffic composition

In order to differentiate different behaviors in VISSIM, four vehicle “classes” were formed. Classes allow the micro simulation programmer to specify certain behaviors, rights and restrictions to a group of vehicles. Classes can involve multiple vehicle types or just a single type. Four classes were established: cash cars, E-ZPass cars, cash heavy vehicles and E-ZPass heavy vehicles. Car classes had one vehicle type, cars, with default characteristics of width, length, acceleration. Heavy vehicles had a mixture of single unit, bus and tractor trailer units with default characteristics. The quantity and distribution levels of these classes are assigned in the traffic/vehicle composition menu and were determined by field data. The vehicle compositions and desired speeds are demonstrated.

V. RESULT, 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 exits 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 has 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 number 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.

Injury Status
One sixth of all crashes resulted in an injury. Remaining crashes were deemed non-injury which could be attributed to the low speeds at toll plazas. Twenty collisions a year were more serious and inflicted bodily harm. Low incapacitation numbers provide relief that collisions are relatively minor.

Age
Driver's age often surfaces when discussing human error in at fault crashes. Surprisingly, young and old drivers, the two categories of drivers typically most at risk, had the lowest crash occurrences. Highest rates came from the 20-40 year old range, with a significant decline in middle aged drivers. Further detailed age analysis of this age group yielded no significant trends but higher rates from young twenty-year-old.

Manner of Collision
Crash type analysis returned high rear-end crash numbers as expected at toll plazas where queuing is common. Sideswipe incidents are also understandable due to merging zones prior to and following the toll booths. A high number of single vehicle crashes seems to signify collision with either infrastructure or other form of the driving environment. Rear-end collisions at toll plazas are typically the result of driver inattention, following too closely or exceeding reasonable speeds.

Vehicle Type
Vehicle type could signify to toll plaza safety issues if a particular vehicle body type was over represented in crash analysis. In this circumstance, passenger cars including light duty pickups were the common vehicle in collisions. Tractor trailers account for 1 in 8 crashes but are not necessarily more or less at fault. It wou environments would learn the safest and most efficient paths of least resistance or lane changes. Vehicle type data by itself does not provide any grave insight into crash trends.

Driver Contributing Code
Stemming from manner of collision results, rear-end results and sideswiping collisions are the product of following too closely and failing to yield or straying out of a lane. Interestingly enough, distraction and inattention are highly at fault as well with almost 40 percent of contributing actions. Distracted driving is a problem on every form of roadway but highly important at toll plaza junctions due to the rapid decision making required at these facilities. Signage, lane assignments and other vehicles all compete for drivers focus and mental resources. Inattention may be mislabeled as distraction or vice versa in some instances. However, unnecessary fault may be placed upon drivers if when operating under control and as expected the environment introduces confusion and risk. Excessive or inopportunely placed signage may be consuming more resources than necessary for the benefit of the end user's information on lane and payment type. Many states have adopted the policy of accepting any form of payment at every lane to avoid confusion and panic by drivers.

In field observations, drivers infrequently come to complete stops in dedicated ETC lanes. In some rare incidents they will backup and traverse to cash or manual lanes to complete their payment. This poses a risk to that vehicle and every other vehicle approaching the plaza. Other drivers may not understand the intentions of a misguided vehicle and cause a chain of unpredictable and dangerous maneuvers to adjacent or following cars. A solution for this problem may be to employ a policy accepting all payment forms.

Injury Status vs. Plaza
Interchanges at Weston (I-95) and Boston Extension (Newton) had the highest number of injury related crashes. These three collocated plazas were also the highest crash rate plazas in the state as well, which provides little credible evidence of out of the

ordinary operations. Further exploration into manner of collision and contributing actions by the "at fault" driver may shed light into environmental influences at these busy plazas. Interchanges 14, 15, 16 are all large in size with seven or more lanes to choose from one approach. Current lane assignments have distributed ETC lanes on boundary lanes and manual lanes in the center. However, none of these plazas employ multiple payment methods.

Manner of Collision vs. Plaza

Rear-end crashes are most common at high demand plazas. Generally, the number of lanes a plaza has, directly correlates to a higher rate of angle and sideswipe collision potential. Larger plazas have a tendency to have more sideswiping collisions, but with such a small sample size of crashes, this relationship cannot be officially verified with any significance.

Time vs. Injury Status

Commuting hours proved to be most harmful with over 25 injury related crashes between the AM and PM peak travel hours during the analysis period. The overnight hours were low in crashes and few in injuries. While speeds may decrease due to congestion on highways, injuries remain an issue during most daylight hours

V. Further Research

Although the completed research provided significant insight on varied toll plaza operation and safety, additional research questions remain. Completion of thesis tasks resulted in several recommendations on where to expand research of these highway environments. Integration of a driving simulator would be a logical next step to evaluate driver decision making for several reasons. Eye trackers are one feature of most modern driving simulators, which provide visual insight into driving behavior. While drivers approach plazas they tend to scan for signage, other vehicles on their route to an optimal lane by weighing lane changes to queues and payment methods. By gauging human factor trends and time spent on these tasks, engineers could better design toll facilities. The VISSIM model developed as part of this thesis effort utilizes many aspects of the microsimulation software, but could be improved for wider applicability. The addition of varying traffic conditions and demand, and open road tolling lanes would allow this model to simulate most toll plazas in existence today. The microsimulation model had parameter limitations of the discrete choice model. Future research would involve programming an application programming interface (API). A programmed driver decision model could be easily modified to add driver parameters as research in the toll environment expanded

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