Evaluation of Open Road Tolling and Express Lanes on Toll Road Facilities
REVISED

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ABSTRACT

Improvements have been sought to decrease toll transaction times so that drivers experience reduced delays or none at all. Many toll authorities have already implemented automatic vehicle identification (AVI) ITS technology in the form of electronic toll collection (ETC), but increasing traffic volumes are prompting the necessity to explore better ways of utilizing technology to benefit toll customers. Mixed-use ETC and dedicated ETC lanes have improved plaza performance and now open road tolling with the elimination of plaza barriers is being implemented as the evolution of ETC continues. This allows toll transactions to take place at highway speeds and reduces potential conflicts between drivers. A number of agencies around the world have implemented open road tolling and some have integrated express (high speed) ETC lanes in their normal plaza design. The implementation of open road tolling with express lanes for the University Plaza case study in Orlando, Florida reduced delay for manual cash customers by an average of 7 seconds, for ACM customers by 6 seconds, and increased the speed for ETC customers by 57% in the dedicated ETC lanes. The simulated scenarios for the 5 year forecast of traffic volumes concluded the performance of the plaza with the previous configuration of the cash lanes would drop significantly. However, the ETC lanes were simulated as express ETC lanes (55 mph) and adequately accommodated the increase in volumes for those lanes.

INTRODUCTION

Transportation engineers and planners, through the use of innovative technologies, are seeking alternatives to improve performance at toll plazas and relieve traffic congestion on toll facilities in the United States and throughout the world. Toll roads are roads where motorists are charged a fee (or toll) to use the facility (1). The location where these tolls are collected, traditionally toll plaza structures, cause delay to drivers since they must stop and pay the toll. Improvements have been sought to decrease the time of each toll transaction so that users experience either reduced delays or no delays at all.

Although many toll authorities have already implemented automatic vehicle identification (AVI) ITS technology in the form of electronic toll collection (ETC), increasing traffic volumes are causing these officials to seek even better ways to utilize technology to benefit their customers. Although mixed-use lanes (conventional toll lanes equipped with ETC technology) and dedicated lanes (ETC equipped customers with speed limits imposed) have been widely used on toll facilities, open road tolling eliminates existing plaza barriers and creates a new toll road design that mitigates congestion (2). Open road tolling is fully automated electronic tolling in an open road environment allowing vehicles to travel at normal speeds when passing through toll collection points (1).

Toll Lane Types

Prior to the development of ETC technology, the only accepted ways to improve the traffic operations at toll plazas were to construct additional lanes or increase capacity by decreasing the time of each transaction through use of tokens or coupons. It was noted that throughput capacity was not dramatically increased from these improvements and the costs for making these changes were expensive and nearly impossible where additional right of way was not available (3). An example is the Illinois Tollway, where three plazas were widened from an average of 10 lanes per direction to an average of 15 lanes per direction as part of an extensive capital construction program. Despite widening the plazas, which managed to improve traffic flow, three other plazas were identified as needing widening and five other plazas were impossible to widen substantially. These additional improvements were becoming very costly. Plaza problems on the Illinois toll road cannot be solved by constructing more lanes and other solutions are needed.

The five types of toll plaza lane transactions currently in use on the OOCEA system include manual (with toll attendant), automatic coin machine (ACM), mixed conventional with ETC (mixed ETC), dedicated ETC and express ETC (4). Conventional toll lanes (manual or ACM toll lanes) require all drivers to stop at the plaza and tolls are paid manually. Mixed ETC lanes combine ETC capability with either manual or ACM service thus providing additional lane selection for ETC users. Dedicated ETC lanes do not provide service for conventional toll collection and are typically positioned at the center lanes of the mainline toll plazas. Express ETC lanes are physically separated (i.e. barrier) from the other types of lanes and allow vehicles to drive at free-flow speeds (55 mph (88.5 kph) or more.

A report in 1993 identified four issues for deciding between dedicated ETC versus mixed ETC lanes for AVI implementation (4):

1. Capacity by lane type
2. Relationship of speed to capacity
3. Levels of AVI participation
4. Thresholds for toll plaza lane configurations

Of the five toll lane types (manual, ACM, mixed ETC, dedicated ETC, and Express ETC), the capacities for mixed ETC, dedicated ETC and express ETC were identified as 700, 1200 and 1800 vehicles per hour, respectively. These capacities are largely attributed to the approximate speeds in which vehicles use these lanes. The average speed for these lane types were 7, 15 and 55 mph (88.5 kph), respectively. Therefore, according to this report, it was proven that there is a relationship between speeds and capacities for toll lanes (4).

ETC Technology

AVI is a technology system using transponders on vehicles and external sensors to determine if vehicles in toll lanes are carrying a valid transponder and to identify that vehicle's classification. This technology allows toll transactions to take place based on this information. Transponders are electronic tags mounted on the vehicle that automatically assess the amount of the user fee. ETC is the use of AVI technology to allow more efficient collection of tolls and it deploys various communications and electronic technologies to support the automated collection of payment at toll booths and other collection points. Collectively, the application of ETC technologies increase system throughput, improve customer service, enhance safety, and reduce environmental impacts (1). The following are formal definitions of the technologies (1):

- *Automatic Vehicle Identification (AVI):* A technology system using transponders on vehicles and outside sensors to determine if vehicles on toll lanes are carrying a valid transponder and what the vehicle's classification is (truck vs. passenger car, SOV vs. HOV). This system also processes the appropriate toll transaction based on the information.
- *Electronic Toll Collection (ETC):* Systems deploying various communications and electronic technologies to support the automated collection of payment at toll booths and other collection points. Collectively, the application of these technologies increase system throughput, improve customer service, enhance safety, and reduce environmental impacts.
- *Toll Violation Camera:* Fixed, short range, still cameras used to obtain single frame pictures which are deployed in individual lanes at tolling points. Toll violation cameras are aimed and focused to obtain images of the license plates of violating vehicles.
- *Transponder:* An electronic tag mounted on a license plate, built into a vehicle, or placed on the dashboard. The tag is read electronically by an electronic tolling device that automatically assesses the amount of the user fee.
- *Vehicle Separators/Profilers:* An AVI system component located on a gantry or at the side of a lane. They perform functions similar to light curtains. The class of vehicles is determined based on the profile of the passing vehicle.

Dedicated ETC lanes utilize the conventional toll plaza lanes at low speeds and are only provided for vehicles equipped with proper transponders. Dedicated lanes have largely been instituted as a retrofit to existing toll plazas in order to increase the capacity of the plaza without the need for major reconstruction or adding additional conventional (attended or automatic) lanes. In 1995, many toll-road authorities and operators were primarily investigating low-speed dedicated ETC lanes to improve their existing facilities with relatively small expense (3).

Two methods for providing nonstop toll collection are dedicated ETC lanes and express ETC lanes. The following definitions provide further explanation for lane types (1):

- *Express Lanes:* A lane or set of lanes physically separated, usually with a barrier, from the general-purpose capacity provided within major roadway corridors. Express lane access is managed by limiting the number of entranced and exit points to the facility. Express lanes may be operated as reversible flow facilities or bi-directional facilities.
- *High-Occupancy Toll Lanes (HOT lanes):* Managed, limited-access, and normally barrier-separated highway lanes that provide free or reduced cost access to HOVs, and also make excess capacity available to other vehicles not meeting occupancy requirements at a market price.
- *Open Road Tolling:* Fully automated electronic tolling in an open road environment allowing vehicles to travel at normal speeds when passing through toll collection points.

Express Lanes

Express ETC lanes are physically separated from all other toll lane types and permit free-flow speeds through the toll collection point. These lanes completely bypass the conventional toll plaza and speeds equal to or greater than 55 miles per hour have typically been allowed. Whether or not to replace conventional or mixed lanes with either nonstop method (dedicated vs. express lanes) largely depends on the levels of ETC participation and proper toll plaza lane configurations. Construction of express ETC lanes at existing facilities requires more right-of-way and could also require changes in the approach and departure roadways as well as consideration of interchanges (3). Open road tolling utilizes the express lane concept since it employs fully automated electronic tolling and allows vehicles to travel at normal speeds through each toll collection point along the facility.

Open Road Tolling

According to an article in ITS America, toll road infrastructure during the past 14 years has experienced three basic phases and is just entering a fourth phase (2). During the first phase, toll plazas with lane barriers and manual toll collection were constructed. The second phase introduced the use of automatic coin machines for collecting tolls at the plazas. During the third phase toll authorities began adopting ETC technology to supplement and/or replace manual and ACM lanes. This type of retrofit typically required users with transponder-equipped vehicles to slow down and follow one lane through the toll plazas. The fourth phase is the introduction of open road tolling (ORT) which has its own distinct technical and operational challenges, such as:

- Tracking vehicles in a multi-lane situation, where lanes are not divided by concrete islands, as is the case with the traditional toll plaza. In open road tolling, painted stripes designate the division between lanes.
- Handling random traffic patterns.
- Correlating data from the different ETC subsystems with the right vehicle
- Maintaining system accuracy over a wider speed range
- Performing maintenance actions

Implementation of Open Road Tolling

Raytheon is developing an open road Electronic Toll collection and Traffic Management (ETTM) system in Israel for a new north-south highway that was scheduled to open in the summer of 2002 (5). This new ETTM System incorporates several innovations, such as real-time enforcement and the use of transponder data by the incident detection algorithms in the traffic management subsystem.

The Highway 407 Express Toll Route (407 ETR) in Toronto, Canada, was the world's first open road with an all-electronic toll collection system (6, 7). This facility was designed as an express bypass to the north of the Greater Toronto Area which provides an alternate route for drivers that do not want to experience congestion on Highway 401. By using transponder technology and digital imaging recognition systems, conventional toll plazas were eliminated and this allows users to pay their tolls without stopping. Tolls are collected at regular highway speeds and tolling stations are located at exits and entrances to the highway. Electronic sensors located on each overhead gantry log each vehicle's entry and exit to the system. Vehicles without transponders are identified with a license plate recognition system and charges fees accordingly. Currently, the 407 ETR has a total of six lanes with the capability to expand to ten lanes.

Other agencies in Oklahoma, Georgia, Texas and New Jersey are employing open road tolling and high-speed toll lanes (2, 8). Oklahoma and Georgia were early adopters of open road tolling upon recognizing that improvements could me made in vehicular mobility, increased capacity and elevated efficiency for toll road operators. Oklahoma's PikePass toll system is comprised of 278 toll lanes that cover 560 miles. Georgia's cruise card lanes have been highly utilized on their toll road with 14 ETC lanes. The North Texas Tollway Authority (NTTA), which was the first organization in North America to employ ETC, completed their changeover to open road tolling in just six days at one of Dallas' busiest locations. The New Jersey Turnpike has planned to build an interchange at Exit 1 in Carney's Point which will employ some high-speed E-ZPass lanes. Slated to open in 2003, originally these lanes were supposed to be dedicated E-ZPass only lanes that could be converted to two high-speed lanes in each direction. Instead, the New Jersey Turnpike decided to implement high-speed lanes right away and they are estimated to allow drivers to drive at about 50 mph through the interchange. The NJ Turnpike already has high-speed toll lanes at Exit 6 in Florence, where drivers are allowed to drive at 45 mph.

Another location that is using express lanes is in Orange County, California (9). The Orange County Transportation Authority (OCTA) acquired the 91 Express Lanes franchise rights from the California Private Transportation Company (CPTC) in January 2003. The 91 Express Lanes are a four-lane, 10-mile toll road extending from the Orange/Riverside County line west to SR-55. Depending on the time of day, some users of this facility have reported a savings of up to 40 minutes in travel time. The 91 Express Lanes employ variable pricing which is intended to maximize the number of cars traveling through the Express Lanes at free-flow speeds. Prices during "super-peak" times are increased when there is high congestion. The concept of value pricing is used as a demand management tool.

Open road tolling has also been proposed in the Miami-Dade Expressway Plan (10). Only users with SunPass will be able to use the new Central Parkway which will become the sixth expressway for the Miami-Dade Expressway Authority. The Central Parkway is a new 8-mile north-south corridor meant to be an extension of the Dolphin Expressway, which is located west of the Turnpike. The Miami-Dade region was rated 14^{th} highest in total congestion costs among 68 urban areas, according to an Urban Mobility Study cited in January 2003. Therefore, agencies are seeking ways to alleviate this traffic congestion in the region. The Central Parkway will employ open road tolling which will prevent delays since drivers will not have to stop and pay tolls at toll booths. This limited access facility will not employ any toll booths along the 8-mile corridor and will only allow customers with SunPass to use the expressway.

The Turnpike Enterprise in Florida is very interested in employing new technologies and also has plans to implement open road tolling (ORT) on the Sawgrass Expressway (11, 12). The Turnpike Enterprise seeks technology that has the potential to improve the level of service to customers and sees the Sawgrass Expressway as an ideal roadway for implementing these technologies. Currently, there are existing peak-hour capacity constraints on the expressway, it is an isolated system, there is a high percentage of commuter traffic, and there are operational issues with the mainline toll plazas. These roadway characteristics and other issues were the reason the Sawgrass Expressway was selected for making these changes. Based upon the final recommendations from feasibility studies involving open road tolling (ORT) and value pricing, the Turnpike Enterprise has plans to use these technologies on the Sawgrass Expressway. With ORT, there would be no toll plazas, no toll collectors, and no lane restrictions. Customers would pay their tolls while traveling at highway speeds. Benefits of ORT include eliminating customer delays, providing more equitable tolls and improving customer safety and traffic operations. Safety would also be increased for agency personnel due to the elimination of the traditional toll plaza.

In conjunction with ORT, value pricing is also being considered for implementation on the Sawgrass Expressway (11, 12). Value pricing is an emerging demand management strategy which can be used to manage expressway capacity, especially during peak traffic periods. Value pricing can be defined as "A system of optional fees paid by drivers to gain access to alternative road facilities providing a superior level of service and offering time savings compared to other facilities". Pricing types would include: time of day, occupancy and dynamic pricing based on the level of congestion. In February 10^{th} 2003, the Suncoast Parkway in Tampa was opened and features 42-miles of Sunpass only express lanes. Two northbound and two southbound express lanes will allow users with transponders to travel through without stopping for tolls.

Plans are also underway to incorporate express lanes (Xpress lanes) in the I-4 corridor. The Turnpike Enterprise has plans to construct four Xpress lanes in the center of I-4 that will employ variable pricing. The tolls for using the Xpress lanes will vary depending on the level of congestion experienced on the rest of the facility. Dynamic message signs will indicate to drivers the toll fee so that they can make a decision whether or not to continue using the non-toll lanes or use the Xpress lanes for a potential savings in travel time, by avoiding congestion on the roadway. The Xpress lanes will provide limited access and will allow entry and exit from the facility at specific points along the I-4 corridor.

OOCEA Network

The Orlando-Orange County Expressway Authority (OOCEA) provides more than 90 miles of interstate standard roadway to drivers in Central Florida. Currently, the network consists of eleven mainline toll plazas and with corresponding on and off ramps. Beginning in 1994, The ETC technology called E-PASS was introduced to one main plaza and accompanying ramps at a time. At this early stage, only mixed lanes were provided, in which ETC vehicles used the same lanes as cash paying customers. Dedicated ETC lanes were eventually introduced at the busiest plazas and implementation was largely dependent on E-PASS participation. Some dedicated ETC lanes have recorded throughput in excess of 1,850 vehicles per hour, which is approximately four times the capacity of a conventional toll lane (13, 14). Although these dedicated ETC lanes have substantially increased the capacity of the existing toll plazas and managed to defer construction of additional conventional lanes to meet traffic demand, the OOCEA has decided to implement open road tolling to further benefit customer relations and potentially increase capacity.

The first road in the OOCEA system was introduced in 2001 on State Road 429 (Western Expressway) (15). SR 429 is a 10.6-mile (17.06 Km), $237-million, limited-access tolled expressway that was the first in the state of Florida to feature express lanes and open road tolling. The purpose of constructing this plaza was to provide a new design where higher speeds could be safely achieved. Design concepts were first discussed in 1996 and today this mainline plaza features five toll lanes per direction (three manual, two express) and utilizes the E-PASS electronic toll collection transponder system. The concept of keeping slower drivers to the right and high speed to the left was incorporated into the design of this facility. E-PASS customers remain on the mainline highway and conventional payment customers exit to the right and use a traditional plaza. Then these vehicles return to the mainline highway. Detailed design of the toll plaza itself was also a consideration. The OOCEA decided against providing a tunnel underneath the express lanes, since this tunnel would need to be even longer than the other plazas and since the high water table is a concern in Florida. Instead, the OOCEA decided to provide a pedestrian bridge to facilitate crossing and in order to hang equipment.

Case Study

A mainline toll plaza in Orlando, Florida was recently renovated to include express ETC lanes. The University plaza was the first of the OOCEA's existing plazas to undergo a retrofit to install express lanes and implement open road tolling. This plaza was selected first since it has the highest percentage of E-PASS customers (greater than 60% during the peak hour). The purpose of this project was to increase cash lane capacity and add express lanes. The OOCEA has plans to retrofit all of their mainline toll plazas to incorporate express lanes by the year 2007 (16).

Prior to construction that commenced in March 2002, the University plaza operated with eight toll lanes open during the peak periods. Reversible dedicated ETC lanes allowed the plaza to operate with 5 lanes in one direction (two manual, one ACM, and two dedicated ETC lanes) and three toll lanes in the other direction (two manual and one dedicated ETC) during the peak periods of traffic. Normal operation provides four toll lanes per direction (two manual, one ACM, and one dedicated ETC). Speed limits of 35 mph (56.3 kph) were imposed on all dedicated ETC lanes and these lanes are located adjacent to the cash paying lanes (manual and ACM). ETC lanes are placed to the left at mainline toll plazas to conform to standard highway practice in which slower traffic is kept to the right and faster traffic to the left. This prevents faster drivers weaving in front of slower drivers.

Construction took place under heavy traffic conditions and began by installing four additional cash lanes (two per direction) on each side of the toll plaza. In addition, one approach lane was added in the northbound and southbound directions to expand the roadway. Then the middle lanes of the toll plaza were demolished and removed in order to make room for the express lanes. The express lanes were elevated in order to accommodate the 70 mph (112.7 kph) design speed. The current posted speed limit during the data collection was 55 mph (88.5 kph).

Implementation of open road tolling did improve the operational performance at the University Mainline Toll Plaza. The evaluation period spanned a period of 16 months between years 2002 and 2003 during the peak traffic hours (7-8 AM and 5-6 PM). The parameters used to evaluate the performance included measures of effectiveness commonly used for toll plaza operations measurements such as throughput and delay.

The analysis was separated by peak hour and direction because there was a difference in the number of approach lanes for each direction. The northbound direction had only two approach lanes which created some performance deficiencies prior to the completion of the new plaza design. Table 1 summarizes the results of the analysis throughout the entire 16 month study period.

Case Study Results

Prior to the beginning of construction on the plaza, the average throughput of the plaza was 6000 vph for both directions. The directional split during the peak periods were 64/36. The southbound traffic was heavy in the AM and the northbound heavy in the PM. However, demand would increase significantly for the PM southbound periodically due to influence from the Sanford International Airport, which is north of the plaza. Due to the observation of this occurrence, data was also analyzed for this time/direction to evaluate the plaza under conditions of high demand.

The time period data was collected before construction is referred to as Spring 2002. Sample data was also collected during construction to monitor the performance of the plaza. These time periods were Fall 2002 and Spring 2003. Summer 2003 is the data collection period after the renovation of the plaza was completed.

Fall 2002 was a split plaza configuration. Demolition of the previous cash toll lanes made it necessary to split the traffic. There was a sign upstream of the plaza indicating to the customers that there were cash only lanes to the right of the plaza and ETC lanes to the left of the plaza. Though not indicated on the sign, there was a single manual lane adjacent to the ETC lanes on the left also. One additional approach lane in each direction was completed during the Spring 2003 data collection period but did not provide additional toll lanes yet.

In Spring 2002, the total delay of cash vehicles at the plaza during a peak hour averaged just over 4.5 hours for the southbound and just over 5 hours for the northbound. It was also observed that the provision of only two approach lanes was creating a bottleneck upstream of the plaza. Though the average delay of a manual vehicle northbound was slightly lower than southbound, the average delay of an ACM customer was higher and the overall number of cash customers was higher.

The Spring 2002 PM-southbound had only 3 lanes operational during the peak hour. This direction would also experience significant increases to demand due in part to airport traffic. The level of demand exceeded the ability of the plaza to service the customers adequately and as such, the delays were tremendous. The queues for the cash customers were observed to be as long as 55 vehicles during the period of highest demand. A cash customer could expect to wait an average of almost 4 minutes. The reduction in throughput for the ETC lane (only one in this time/direction) was attributed to the cash customers inhibiting the flow of the dedicated lane upstream of the plaza.

During the Fall 2002 period, the split lane configuration reduced the effect of cash customers on the ETC customers. The throughput increased for the ETC lanes and the average inter-vehicle time dropped. The inter-vehicle time is the time between departures of two vehicles. The plaza delay also dropped. However, the percent of ETC use showed a slight increase which could influence the overall plaza delay.

In the Fall 2002 PM southbound, the utilization of the cash lane adjacent to the dedicated ETC lane was low compared to the other cash lanes and the throughput had also increased. The throughput increase was attributed to the addition of a 3rd cash lane (adjacent to the ETC) and the separation of the ETC customers from the greater portion of cash customers, which reduced the influence of them on the ETC customers.

The AM-southbound delays for Spring 2003 had a slight increase in total plaza delay possibly due to the change in the plaza configuration which now had three open cash lanes on the right (2 manual and 1 ACM) and 2 dedicated ETC lanes towards the left. The PM-northbound direction had very increased to delay for the cash customers. This is attributed to the additional approach lane for the northbound direction. This additional lane increased level of demand at the plaza and thus increased the length of the previous bottleneck downstream to the plaza.

After construction for modifying the plaza to the open road tolling concept, the delays at the plaza decreased considerably. Compared to the conditions prior to construction, the average delay for a manual cash customer decreased by an average of 6 seconds southbound and 8 seconds northbound. An ACM customer's average delay decreased by 2 seconds southbound and 10 seconds northbound. Due to the additional lanes now provided for both directions, the plaza will now be able to accommodate drivers during periods of high demand in either direction.

The 85th percentile of individual vehicular delay has been proven to be a better evaluation of the plaza's performance, therefore, this value was also included (17, 18, 19). A letter designation (A-F) was also established to indicate a performance level (17, 18). LOS A=14 sec/veh, B >14 and =28 sec/veh, C >28 and =49 sec/veh, D >49 and =77 sec/veh, E >77 and =112 sec/veh, F>112 sec/veh. This evaluation was able to recognize the variation in lane type performance where the average delay did not (i.e. Spring 2002 PM-NB). These results support the conclusions of the performance evaluations herein. The LOS is measured at A for both directions for the current plaza conditions.

A simple evaluation of capacity for a plaza lane can be determined using one of two methods previously identified by Al-Deek et al. (17, 18, 19). A measured capacity utilizes the throughput of a cash lane during a period of constant queue upstream of the plaza. An ETC lane's capacity can be measured using a period of its highest throughput (i.e. consecutive peak 20 minutes). When the criterion was met for measuring the capacity of a toll lane, the value was used to determine a total capacity for that lane type which considered the number of lanes available during the analysis time period. For instance, in Spring 2002, there were two dedicated ETC lanes. The capacity of one ETC lane (1977 vph) was computed and multiplied by two.

For the ETC lanes, the capacity reduction for the PM-southbound was attributed to the constraints created on the ETC customers from the high demand for the cash lanes. The capacities measured during construction compared to those in Spring 2002 concluded that the construction had a negative effect on the traffic at the plaza. Due to the significant improvements to the plaza performance in Summer 2003, no evaluation of capacity was able to be completed. However, based on the observations made in the field at this plaza during the entire study period on the operations of the dedicated ETC lanes including the video analyses, capacities are expected to increase beyond those calculated for the previous 35 mph (56.3 kph) speed limit lanes.

Some of the data supporting this are the results of the previous throughput and recorded average inter-vehicle times which for the express lanes are similar but the average inter-vehicle time was 2 seconds or slightly under during constant throughput of the express lanes. Furthermore, the express lanes did not have extended periods of constant throughput based on the video analyses. Therefore, it is anticipated that as the volumes of ETC users increase, these express ETC lanes will be able to provide service for a high number of customers per hour.

Case Study Simulation Analysis

In order to complete some further evaluations of the new plaza design, the TPSIM computer simulation model was run. TPSIM is the Toll Plaza Simulation model developed by the University of Central Florida's Transportation Systems Institute. This stochastic, microscopic simulation model was previously validated and its transferability tested using actual collected field data (20, 21). The model was calibrated with 3 days of field data from the Spring 2002 collected data.

TPSIM was used to conduct a small experiment and run scenarios for the University Toll Plaza. Scenario 1 represents northbound-PM and Scenario 2 represents southbound-AM directions, respectively, for the current plaza configuration. These are considered the base scenarios. A total plaza hourly volume of 3800 vph was used as the model's input volume. This input volume is an overall average of throughput derived from all available peak hour days (AM-southbound and PM-northbound) of the before study (Spring 2002). The input parameters for these "base" scenarios were to represent a typical day at the plaza during Spring 2002. In these scenarios, the ETC speeds are 35 mph. A total of 10 runs (each with a different random number seed) were used to obtain average results for each scenario. In the northbound direction there were two approach lanes and the southbound direction had three lanes.

Scenarios 3 and 4 are simulations with a year 2007 traffic volume projection of 5965 vph. The percentage of traffic volume growth during the last five years was used to calculate an average annual traffic growth of 9.44% (16). The following traffic characteristics were kept constant so that the effects of changing the number of approach lanes and ETC speeds were isolated.

Geometric characteristics:

- Approach lane length (2500 ft)
- Lane width (12 ft)
- Toll lane length (600 ft)
- Transition zone length (200 ft)

Global Parameters and Traffic Characteristics:

- Inter-arrival distribution
- Minimum headway
- Percentage lane changing
- Reaction time (minimum and maximum)
- Approach speed (average and standard deviation)
- Deceleration rate (average and standard deviation)
- Acceleration rate (average and standard deviation)
- Clearance
- Percentage of vehicle type
- Percentage of vehicle class (trucks)
- Service time distributions

Scenarios 1 and 3 were compared for the northbound direction. The overall throughput increased by 49.58%, average queuing delay for the ACM lanes increased by over 80 seconds, and the average queuing delay for the manual lanes increased by over 90 seconds. The total queuing delay for the plaza increased from under 5 hours to over 31 hours. Scenarios 1 and 3 were compared for the southbound direction. The overall throughput increased by 36.26% and average queuing delay for both the ACM and manual lanes increased by over 150 seconds. The total queuing delay for the plaza increased from under 5 hours to over 48 hours. The increased demand for the ETC lanes was adequately serviced from the implementation of the express ETC lanes (55 mph).

CONCLUSIONS

Development of the toll road infrastructure is now in the middle of a phase in which open road tolling (ORT) is being utilized on transportation facilities throughout the world. The benefits of ORT include elimination of the plaza barrier, toll transactions that take place at highway speeds (customers are not required to reduce their travel speed), possible increase in customer satisfaction, and the potential for increasing capacity. It is likely that customer relations will increase since drivers using ETC on these ORT facilities should not experience any delays at all and will not be required to slow down while passing through the toll collection locations.

One expansion of open road tolling is express ETC lanes with ORT that is being used for limited access facilities. Express ETC lanes are either provided at new toll plaza collection points or are being constructed at existing plazas to replace current speed-controlled dedicated ETC lanes. Many limited access facilities now only allow users equipped with transponders to use the facility or use technology to identify license plate numbers. Limited access facilities employ ORT so that transactions take place without using a traditional plaza barrier.

The Orlando-Orange County Expressway Authority recently renovated one of their existing mainline toll plazas. A case study that evaluated plazas operations prior to the construction of express ETC lanes and after renovation was reviewed to support the use and implementation of the ORT concept. The University Mainline Toll Plaza was the first of the OOCEA's existing toll plazas to undergo a retrofit in order to increase cash lane capacity and add express ETC lanes. The performance of the plaza was evaluated based on measures of effectiveness such as throughput and delay. The implementation of open road tolling for University Plaza reduced the delay for manual cash customers by an average of 7 seconds and for the ACM customers by 6 seconds. Though capacities were not able to be evaluated after the plaza was completed, the express ETC lanes are expected to increase due to the increase in the speed limit.

In addition to analyzing field data, an experiment using TPSIM was also performed in which four scenarios were used to evaluate the change by direction of the additional approach lanes and increase speed of the ETC lanes from 35 mph (56.3 kph) to 55 mph (88.5 kph) for a five year traffic forecast. The average delay for the cash lanes increased. This would be expected if the plaza configuration for the cash lane service did not change, however the renovation of the University Plaza added an additional ACM lane to accommodate future traffic growth in the cash lanes. The increased throughput of the ETC lanes, simulated as express ETC lanes in the forecast scenarios, was accommodated.

The concluding results from the review of ORT and the use of express ETC lanes are positive. Not only will the use of this innovative concept improve a toll plaza's operations, but it may also improve the safety for drivers approaching and departing from a toll plaza due to the reduction in possible conflicts from the ORT/Express ETC plaza design (22). Implementations of ITS technology concepts continue to improve the conditions for drivers on today's highway facilities and expand the ability to better utilize existing facilities.

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Tables and Figures

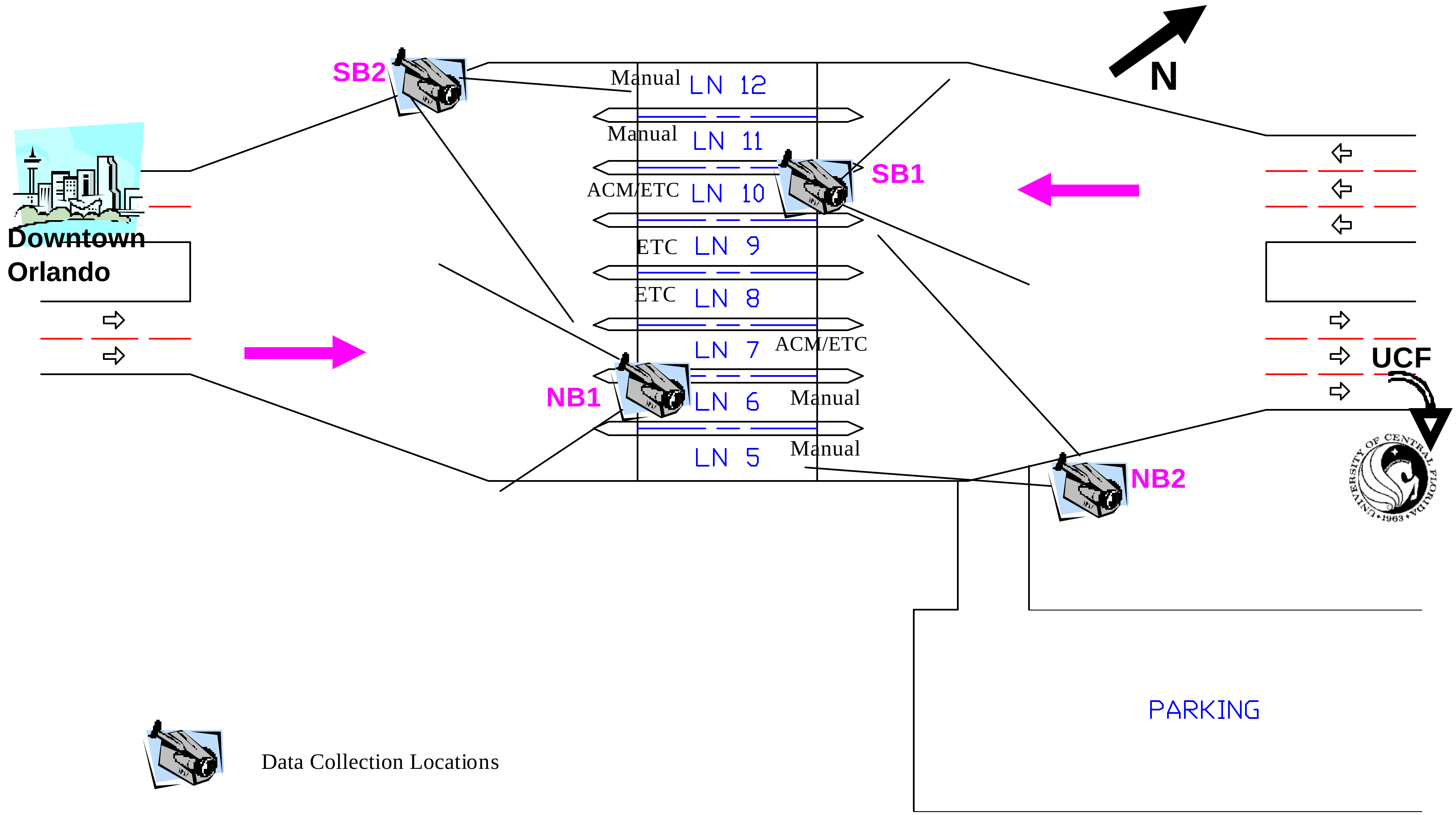

Figure 1. University Mainline Toll Plaza Layout (Before Study)

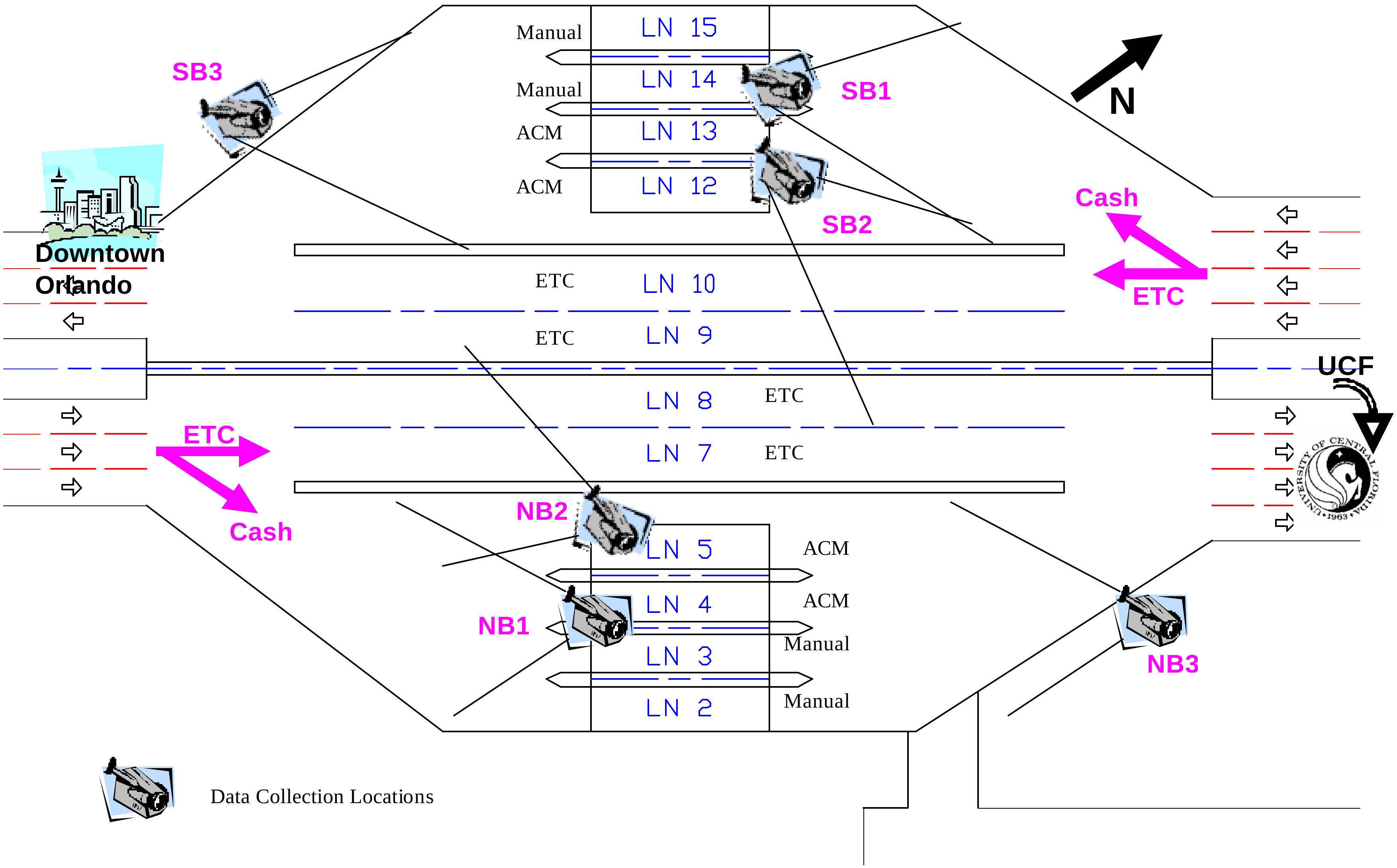

Figure 2 University Mainline Toll Plaza Layout (After Study)

	Throughput (vph)	Avg. Delay	Total Delay	85th% Delay	Avg. Int-Vehicle	Avg. Queue	Max. Queue	Capacity[1]	% ETC
Spring 2002 AM-SB									
ETC lanes	2743	--	--	0:00:00	0:00:03	--	--	3954	100.00%
ACM lanes	501	0:00:10	1:25:54	0:00:16	0:00:07	1	5	661	20.00%
Manual lanes	710	0:00:16	1:35:47	0:00:26	0:00:10	2	5	920	5.62%
Total	3954	--	4:37:27	0:00:10	--	--	--	5535	72.89%
Spring 2002 PM-NB									
ETC lanes	2362	--	--	0:00:00	0:00:04	--	--	3456	100.00%
ACM lanes	504	0:00:14	1:59:17	0:00:20	0:00:07	2	9	561	10.49%
Manual lanes	792	0:00:14	1:36:42	0:00:23	0:00:09	2	5	--	6.15%
Total	3659	--	5:12:40	0:00:13	--	--	--	--	67.34%
Spring 2002 PM-SB*									
ETC lanes	1374	--	--	0:00:00	0:00:03	--	--	1449	100.0%
ACM lanes	--	--	--	--	--	--	--	--	0.5%
Manual lanes	998	0:03:48	7:44:02	0:05:31	0:00:07	30	55	1041	1.3%
Total	2372	--	31:24:02	0:04:01	--	--	--	2490	58.3%
Fall 2002 AM-SB									
ETC lanes	2802	--	--	0:00:00	0:00:02	--	--	--	100.00%
Single Manual lane	291	0:00:07	0:35:35	0:00:07	0:00:12	0	2	--	9.27%
Manual lanes	734	0:00:12	1:14:10	0:00:18	0:00:10	1	5	--	1.91%
Total	3827	--	3:03:56	--	--	--	--	--	74.28%
Fall 2002 PM-SB*									
ETC lanes	1493	--	--	0:00:00	0:00:02	--	--	--	100.00%
Single Manual lane	467	0:00:08	0:56:23	0:00:07	0:00:09	1	6	--	46.44%
Manual lanes	904	0:01:42	12:39:52	0:03:13	0:00:08	12	29	--	1.09%
Total	2864	--	26:16:07	--	--	--	--	--	60.05%
Spring 2003 AM-SB									
ETC lanes	2737	--	--	0:00:00	0:00:02	--	--	--	100.00%
ACM lanes	410	0:00:08	0:56:15	0:00:12	0:00:09	1	5	580	4.61%
Manual lanes	646	0:00:16	1:23:59	0:00:56	0:00:11	4	10	672	1.55%
Total	3792	--	3:44:12	--	--	--	--	--	72.92%
Spring 2003 PM-NB									
ETC lanes	2504	--	--	0:00:00	0:00:03	--	--	3051	100.00%
ACM lanes	543	0:01:06	10:28:23	0:01:34	0:00:07	11	19	--	2.29%
Manual lanes	844	0:01:21	10:07:53	0:02:00	0:00:09	10	19	847	9.03%
Total	3891	--	30:44:08	--	--	--	--	--	66.63%
Summer 2003 AM-SB									
ETC lanes	2832	--	--	0:00:00	0:00:02	--	--	--	100.00%
ACM lanes	479	0:00:08	0:29:10	0:00:10	0:00:16	1	2	--	2.57%
Manual lanes	566	0:00:10	0:44:05	0:00:14	0:00:13	1	3	--	0.80%
Total	3877	--	2:26:29	0:00:06	--	--	--	--	73.46%
Summer 2003 PM-NB									
ETC lanes	2788	--	--	0:00:00	0:00:02	--	--	--	100.00%
ACM lanes	791	0:00:04	0:23:32	0:00:05	0:00:09	0	3	--	35.67%
Manual lanes	734	0:00:06	0:35:59	0:00:10	0:00:10	1	2	--	8.25%
Total	4312	--	1:59:02	0:00:04	--	--	--	--	72.42%

* PM-SB are Fridays, [1] for total # of available lane types (i.e."Manual lanes" capacity includes both lanes)

Table 1 University Plaza Data Analysis Results

	Throughput	Avg Q Delay	Total Q Delay
Scenario 1	2 app lanes/2man/1acm/2ETC (35 mph)		
ETC	2454	N/A	N/A
ACM	492	0:00:13	1:52:52
Manual	756	0:00:14	3:00:21
TOTAL	3703	0:00:14	4:53:13
Scenario 2	3 app lanes/2man/1acm/2ETC (35 mph)		
ETC	2405	N/A	N/A
ACM	485	0:00:13	1:44:38
Manual	742	0:00:14	3:00:30
TOTAL	3632	0:00:14	4:45:08
Scenario 3	2 app lanes/2man/1acm/2express (55 mph)		
ETC	3900	N/A	N/A
ACM	657	0:01:35	17:15:21
Manual	982	0:01:47	14:31:37
TOTAL	5539	0:01:41	31:46:58
Scenario 4	3 app lanes/2man/1acm/2express (55 mph)		
ETC	3403	N/A	N/A
ACM	582	0:02:42	26:01:59
Manual	964	0:02:47	22:24:33
TOTAL	4949	0:02:45	48:26:32

Table 2 University Plaza TPSIM Scenario Output Results