AUTOMATED TOLLS FOR GREECE: SYSTEMS REVIEW AND PERFORMANCE WITH AVC

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ABSTRACT: Typical advanced toll collection systems that combine AVC with multiple payment methods are described, including pilot applications in two toll plazas in Greece which plans to install comprehensive advanced tolling systems on 132 toll lanes. Comparisons of manual and automated tolling are made based on measurements at 10 toll plazas with and without lane processors and automatic vehicle pre-classification. It was found that potential system management gains, reduction of fraud and violations, and the convenience of multiple payment methods are accompanied by elongated service rates.

INTRODUCTION

Toll collection (1) is an area of transportation that has seen many benefits with the deployment of ITS, primarily in the form of electronic toll collection systems (ETC). For example, as of early 1998, there were 29 US metropolitan areas with electronic toll collection systems (2). However, people-operated toll collection is common worldwide and currently is the only form of toll collection in Greece. Most toll lanes in the U.S. are equipped with coin receptors. Person-operated lanes are provided at all mainline plazas. France and Italy have implemented extensive toll systems based on card readers for automated fee or toll collection (AFC or ATC). Card reader-based toll systems can be found in Ohio, Texas, Mexico and several South American and Asian countries.

The Bureau of National Roads of Greece (TEO) plans an upgraded tolling system that provides for manual (operator-based), ATC and ETC transactions. The primary objectives for the upgraded toll collection system are to: (a) Improve the general accountability and productivity of the system; (b) Reduce toll collection fraud; (c) Reduce motorist violations; (d) Offer alternative payment methods; and, (e) Collect traffic data.

General accountability and productivity improvement represents a conversion from a time-consuming and error-prone manual system to a computerized record-keeping system, able to answer fiscal and traffic queries. Toll collection fraud can be reduced to less than 1% by installing an automated vehicle classification (AVC) system that aids operators in charging the correct toll and, if needed, collect data to assist in capturing dishonest toll operators (1). Motorist violations are either non-payment at the plaza or entering at a point past the toll facility. The former can be captured with an image recording and ticket-by-mail system. The latter can be captured at the exit of the tolled segment. In addition to cash payment,
alternative payment methods include the use of credit/charge/bank cards and the use of a custom \textit{TEO} card or a smart card. These alternative payment methods are technologically and operationally well established, so they are not discussed further. The collection of traffic data can be invaluable for applications such as motorway planning, pavement design or rehabilitation analysis, commerce and taxation. Table 1 specifies the findings of advanced tolling applications in the U.S. (3) and their projected applicability to Greece.

This paper focuses mostly on the European style manual/ATC tolling systems. These systems perform AVC to determine the class of vehicle and the corresponding toll based on an established fee schedule. The main components of these systems are described and the results of a service rate survey conducted in 10 toll plazas in Greece, two of which operate with a pilot upgraded tolling system are presented.

\section*{BASIC CHARACTERISTICS}

Typically, highway tolls are distance based and are different for each type of vehicle. Some vehicle classifications are detailed (e.g., Caltrans’ 17 classes) and others are simple (e.g., Toronto Highway 407 defines 3 classes). \textit{TEO}’s toll fee schedule includes 5 classes. Toll systems are either closed or open. In \textit{closed} systems all entrances and exists are tolled. The toll is determined at the exit point based on the point of entry. The Greek motorway toll system was originally a closed system. In \textit{open} systems toll stations are located along segments of the facility; a toll is assessed for each segment traversed. Currently the Greek motorway toll system is an open system like most U.S. tollways.

\textit{Pre-classification} and \textit{post-classification} are applied for vehicle classification on toll systems. Pre-classification vehicle class before the vehicle arrives at the line of payment, which is a booth, coin/token machine, a card-reader, etc. Post-classification determines vehicle class after the vehicle departs from the line of payment. Pre-classification can advise the person or machine collecting tolls about the vehicle class. Post-classification is can confirm the toll charged by the person or machine at the line of payment. Post-classification AVC is more common because it is simpler and has a shorter classification length requirement which enables it to fit existing toll plazas.

Toll lane capacity varies depending on the type of toll collection and other procedures used. The PATH database (3) includes the following types of toll lanes and capacities:

- Person disburses change, issues receipts, etc. = 350 vph
- Person distributes commuter tickets and such= 500 vph
- Automatic coin machine; regular coins only = 500 vph
- Automatic coin machine; some coins, mostly tokens= 650 vph
- Mixed mode, any of the above plus ETC = 700 vph
- ETC, dedicated in conventional toll plaza = 1,200 vph
- Express ETC, dedicated lanes with no barriers = 1,800 vph
Toll data are structured into five hierarchical levels: (1) Toll lane; (2) Each direction of the toll plaza; (3) Entire toll plaza; (4) Regional or tollway-specific center; and, (5) Central facility. Most of the data are collected by the lane processor at each toll lane. Data collected at a toll facility include:

- Tolls collected by lane, traffic direction, type of vehicle, time-of-day, toll lane operator over daily, weekly, monthly and annual periods.
- Vehicular traffic counts for each vehicle class and summaries similar to those for tolls.
- AVC/toll matching for fraud investigation. At the end of each operator shift, a discrepancy analysis is forwarded. Depending on AVC system performance and vehicle mix, discrepancies below a certain threshold (e.g., 1.5%) are not investigated.
- Records of toll lane functions which include: lane open, open to a specific class of vehicles, open for specific types of payment or closed, maintenance and training activities, illegal passages and reversible lane status. Median lanes may be reversible to accommodate unequal traffic demands (i.e., heavy traffic exiting a city on Friday and heavy traffic entering the city on Sunday evening).
- Systems diagnostic data are generated by internal checks designed to alert operators and transfer affected tasks to stand-by equipment, as applicable.
- Violator capture data are produced by the violator capture system. These optional systems may be installed depending on need and cost. The basic system creates a photographic record for manual processing. Upgraded systems include digital license plate recognition and automatic issuance of citation. These systems require laws that enable image-based enforcement and penalty issuance by mail.

AVC SYSTEM DESCRIPTION

This section describes the basic elements of vehicle classification-based automated toll collection and discusses the difficulties associated with the requirements of TEO for:

- Providing all types of payment on all lanes.
- Allowing all types of vehicles on all lanes (e.g., no “Cars Only” lanes).
- Requiring that the AVC is used to define the proper toll fee.

Figure 1 presents the simple pre-classification AVC system available in two toll plazas in Greece. The AVC system consists of optical sensors (photo-electric curtains) and treadles. The optical sensors can be used for vehicle profiling although in the present application they are used to define vehicle height over the front axle as well as vehicle separation and vehicle combinations (truck with trailer or passenger car with trailer, etc.) Treadles are typically used for counting axles. Properly placed and sized treadles can also define whether the axle consists of single or double wheels.

The optical sensors need to be placed as far back as the longest expected vehicle (e.g., about 25 to 30 m prior to the line of payment) for AVC to work properly. This has necessitated a considerable elongation of the toll lanes in the application shown in Figure 1. Furthermore, for the upgraded system, the TEO requires that a patron fee display is
provided so that all motorists (many of whom are visitors during the summer months) have a clear indication of the toll owed; this may cause an additional extension of the toll lane.

The separation of vehicles may be problematic at congested conditions when vehicles may be only inches apart. Modern optical sensors take approximately 4 milliseconds to read an 80 beam curtain completely. If this optical sensor is installed in a manual lane where traffic comes to a stop, since the vehicles’ velocity does not exceed 6 m/sec, the sensor can distinguish two vehicles which are 8 cm apart. Some ETC toll systems require that optical sensors operate with vehicles traveling in excess of 150 km/h. At this speed, certain optical sensors can distinguish between two vehicles which are 30 cm apart. Sophisticated systems combine a radar with the optical sensors. In this way, vehicle profiling can be executed accurately because a continuous speed correction is applied as the vehicle moves (usually decelerates) through the classification zone.

Figure 2 presents an upgraded tolling system similar to those developed by ASCOM-Elsydel for application in “long lane” tollway facilities in France. Nearly identical systems are available by Alcatel, CS Route and GEA of France, Olivetti of Italy, and Sainco Trafico and SICE of Spain; these and component suppliers are listed in (1). Typical control equipment includes the canopy sign, patron display, red/green traffic light signaling the completion of a transaction and visual and audible alarms. Lane barriers are optional; they reduce violations, but impede servicing under busy conditions, increase maintenance requirements and place large loads to power supply systems.

The core of the system is the lane processor which is connected to the operator’s terminal, the printer and the card reader. Typically each lane processor has a real-time connection with the toll plaza supervising server. The lane processor is interfaced to the AVC equipment and the lane control equipment. The AVC equipment consists of the optical sensors, multiple sets of treadles (for axle count, long/short wheel-base assessment and single or double wheel axle determination) and loops for passage and presence detection.

TEO’s requirement for automatic fee collection is complicated because existing booths are of variable size and manufacture. Most are unable to accept card readers in two levels (low for cars and high for buses and trucks). Readers require a large ticket canister (e.g., a canister holding a 5,000 ticket magnetic roll may need replenishment every 2 days) and have a sealed and air pressurized chamber which vents outward to avoid dust, plume and moisture from entering the reader’s electronics and the printer/magnetic encoder. As a result, a separate ATC box is installed, which introduces a second line of payment and the need for a presence loop and software modifications so that the correct fees are collected at the ATC and person-operated lines of payment. This set-up fulfils all TEO requirements.
DATA COLLECTION AND MODELING

Field observations were made at 10 toll plazas spanning about 500 centerline km of the national highway system and having 132 toll lanes. Data were collected in June 1998 under fair weather and moderate traffic conditions to assess the impact of a pre-classification and automated toll system operation. The elapsed time between successive departures from toll booths were measured. While the elapsed time from the 1st to the Nth vehicle in queue at a specific toll lane was being taken, a record was kept of the class of vehicles in the queue, per TEO’s fee schedule which distinguishes vehicles in five classes:

- Class 1 = two and three wheeled vehicles (this class also includes agricultural tractors which are allowed to use the shoulders of highways);
- Class 2 = passenger cars and light duty trucks and vans (with a height of less than 1.3 m, at the front axle);
- Class 3 = 2-axle trucks and buses;
- Class 4 = 3-axle trucks and buses; and
- Class 5 = any combination with 4 or more axles.

The schedule includes the stipulation that trailers towed by cars and light duty trucks and vans are charged a rate equal to that of the towing vehicle. Note the complexity here: a passenger car towing a 2-axle boat trailer should pay twice the class 2 fee, but a poorly tuned AVC system may classify this combination as a Class 5 vehicle. Additional problems include the separation of motorcycles and 3-wheel vehicles from tractors as well as the proper registry of a platoon of motorcyclists entering the toll lane in an overlapping fashion (i.e., they drive partially side-by side on a given lane and they queue properly only a few feet prior to the point of payment.)

Regression modeling was applied to correlate the toll service headways with the vehicle class. In addition, the uphill or downhill departure grade (slope) was noted at each plaza. Two of the plazas are equipped with a basic AVC and automatic receipt issuing system (with a slow thermal printer.) The existence or not of AVC was specified as a variable. Table 2 summarizes the analysis. Model 1 includes only the five vehicle classes, all of which have highly significant parameter estimates. The slope of the departure from the toll booth was introduced in Model 2; it shows that uphill or downhill grade has a significant effect on performance. Specifically, 3% downhill reduces the processing time by about 10 seconds per vehicle, on the average. Model 3 accounts for the presence of AVC installed at two toll plazas. The elongated toll lanes along with the slow printing of the receipts introduces a large and significant delay of about 18 sec/veh, on the average. Model 4 accounts for both the grade and the presence of AVC; it is the best model with highly significant parameter estimates.

All previous models were estimated without an intercept (constant), because no unaccounted for or confounded variables were suspected. Model 5 was estimated with an intercept; the magnitude of the constant is small and not statistically significant which suggests that major effects have not been excluded from the specifications. Also, models
with plaza-specific dummy variables were estimated. Plaza variables were not significant which suggests that the data are not location-dependent. These service times were observed for each vehicle class (model 4): 

- Class 1 = 23.7 sec/veh
- Class 2 = 8.7 sec/veh
- Class 3 = 20.9 sec/veh
- Class 4 = 17.8 sec/veh
- Class 5 = 16.8 sec/veh

The results verify the field experience that the payment by motorcyclists (Class 1) is difficult. Several had to park, unglove and unzip their protective gear in order to pay. The results also indicate that several 2-axle trucks and buses may be under-powered (or overloaded) and have a difficult time accelerating, which extends their processing time. The service time for 3-axle and 4 (or more)-axle vehicles is practically identical. The average capacity of a toll lane without AVC, on level terrain given 100% passenger car traffic is 414 vph without barriers. With a traffic distribution of 0.5%, 90%, 5%, 1.5% and 3% for each of the five vehicle classes, the average capacity per toll lane is about 370 vph. This is practically identical to the 350 vph capacity reported by PATH. For the aforementioned traffic distribution, this base capacity fluctuates by +/-20 vph at -/+3% grade given the 3.7 sec. headway difference which applies mostly to classes 3, 4 and 5.

**IMPLICATIONS AND CONCLUSIONS**

Assuming a level terrain, a slow AVC and toll receipt/inspection system can reduce the capacity to as low as 150 vph per toll lane. Given that the travel time between successive toll plazas in Greece is ½ hour or more, it is estimated that AVC-based tolling will not cause an appreciable delay under low-to-moderate traffic volume conditions. However, under heavy loads, or at times when a sufficient number of toll lanes cannot be opened, serious queuing problems may occur.

Modern AVC-based toll systems do not admit to introducing delays, but the elongated toll lane (causing an earlier drop in speed), the presence of a red signal and barriers, and potential problems with the readers and other equipment is likely to cause some operational efficiency loss. Most tolling authorities, however, outweigh this loss (to the motorists) by their gains in efficiency and centralized oversight, the reduction of fraud and violations and the lessening of workload to operators through the use of alternative payment methods.

**ACKNOWLEDGEMENT**

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**REFERENCES**

1. http://www.ettm.com
A primary benefit is time savings at the toll plaza. An important benefit is the convenience of cash-less transactions. About 60% of the motorists are willing to pre-pay one month’s tolls; about 25% are willing to pre-pay three months’ tolls. Users prefer dedicated rather than mixed-traffic lanes. Users prefer a single system within a region.

<table>
<thead>
<tr>
<th>USA</th>
<th>GREECE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A primary benefit is time savings at the toll plaza.</td>
<td>Except for major holidays and certain weekends, queuing at toll stations is minor.</td>
</tr>
<tr>
<td>An important benefit is the convenience of cash-less transactions.</td>
<td>Tourism and the Euro support cash transact. which are vastly preferred at the present time.</td>
</tr>
<tr>
<td>About 60% of the motorists are willing to pre-pay one month’s tolls; about 25% are willing to pre-pay three months’ tolls.</td>
<td>Pre-payment of tolls is likely undesirable. A magnetic card-based system (with receipt capability) would be more appropriate.</td>
</tr>
<tr>
<td>Users prefer dedicated rather than mixed-traffic lanes.</td>
<td>A similar attitude is expected, but mixed lanes are planned.</td>
</tr>
<tr>
<td>Users prefer a single system within a region.</td>
<td>TEO plans to procure a common system, but privatization or concessions are a threat.</td>
</tr>
<tr>
<td>Users prefer a discount if they decide to invest on AVI equipment.</td>
<td>ERP is a future feature; the present plan requires the facility to “plug-in” ERP.</td>
</tr>
<tr>
<td>Users prefer added uses for the AVI card: Pay parking, bus fares, etc.</td>
<td>This is a complex expansion but many systems have built-in expansion capability.</td>
</tr>
<tr>
<td>The “Big Brother” syndrome has not been an obstacle to electronic tolling.</td>
<td>Most systems offer privacy protection. This is not expected to be a major issue.</td>
</tr>
<tr>
<td>Users fear vandalism particularly if the AVI is installed on the car’s exterior.</td>
<td>Vandalism and theft could be a major issue. AVI can be installed in a concealed location.</td>
</tr>
<tr>
<td>Interest for ETC dropped by more than 10% if AVI units are not transferable.</td>
<td>Since tolls are based on vehicle class, AVI exchange is not desirable (fraud).</td>
</tr>
<tr>
<td>Most users found a $30 transponder cost and $40 deposit cost acceptable.</td>
<td>These prices could be deemed reasonable by most vehicle owners.</td>
</tr>
</tbody>
</table>

**TABLE 1: U.S. motorists’ reaction to automated tolls and applicability to Greece**

**FIGURE 2:** Prototype system by ASCOM-ElSydel which uses pre-classification to determine the correct toll for both manual and automated toll collection.
FIGURE 1: Actual intercity highway toll lane in Greece with basic AVC equipment.

TABLE 2: Manual toll plaza service rates

<table>
<thead>
<tr>
<th>Toll Class</th>
<th>Vehicle Type</th>
<th>M 1</th>
<th>M 2</th>
<th>M 3</th>
<th>M 4</th>
<th>M 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2-WHEEL</td>
<td>28.164</td>
<td>26.019</td>
<td>25.955</td>
<td>23.687</td>
<td>23.787</td>
</tr>
<tr>
<td>2</td>
<td>PAX. CAR</td>
<td>8.976</td>
<td>8.993</td>
<td>8.691</td>
<td>8.704</td>
<td>8.965</td>
</tr>
<tr>
<td>4</td>
<td>3-AXLE</td>
<td>20.838</td>
<td>21.022</td>
<td>17.677</td>
<td>17.829</td>
<td>17.870</td>
</tr>
<tr>
<td>5</td>
<td>4-AXLE</td>
<td>17.640</td>
<td>17.522</td>
<td>16.937</td>
<td>16.805</td>
<td>17.265</td>
</tr>
<tr>
<td>DEPARTURE GRADE</td>
<td>-</td>
<td>3.535</td>
<td>-</td>
<td>3.691</td>
<td>3.867</td>
<td></td>
</tr>
<tr>
<td>AVC</td>
<td>-</td>
<td>-</td>
<td>18.153</td>
<td>18.379</td>
<td>19.875</td>
<td></td>
</tr>
<tr>
<td>Constant (intercept)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-2.61*</td>
<td></td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.921</td>
<td>0.925</td>
<td>0.936</td>
<td>0.941</td>
<td>0.806</td>
<td></td>
</tr>
<tr>
<td>$F$</td>
<td>233.8</td>
<td>205.2</td>
<td>246.6</td>
<td>227.6</td>
<td>59.8</td>
<td></td>
</tr>
<tr>
<td>$N$</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

* = not significant; all others significant at 98% or higher