Conversion to electronic toll collection: a Puerto Rican case study

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The following article is the first of two that will appear in TEC. It describes some of the key issues and challenges faced by a toll authority looking to upgrade from a conventional, manual system to highway-speed electronic toll collection (ETC). This first article is a scene-setter, providing background information to introduce some of the history behind the drive in Puerto Rico towards ETC.

The author is the consultancy team's project manager based in San Juan and he has been working on this multi-million dollar ETC procurement, one of the largest currently being progressed, for the last 18 months. His conclusions may surprise some readers. He reports that the constituent technologies are mature and no longer represent the challenges (or risks) that they once did. Systems integration, he points out, remains a key issue – although, as he describes in the following article, the biggest hurdles to be addressed may be non-technological, such as those relating to institutional, administrative and operational – such as back office – concerns.

PUERTO RICO

Puerto Rico is a small Caribbean island lying 1,000 miles south east of Florida. As a US territory, Puerto Rico is governed largely by Federal guidelines and regulations. As such, this article reports the adoption of ETC technologies from an American perspective, although many of the lessons learned have a far broader application.

Puerto Rico is a densely populated island. Estimates put the population of Puerto Rico at about 3.9 million in 1998/99 [2]. The Island, almost rectangular in shape, measures 100 miles by 35 miles. This equates to an average population density of around 1,100 persons per square mile, a much higher density than for any US state except New Jersey and Rhode Island (and double that for the United Kingdom [3]).

The population has grown from 3.2 million in 1980[4] and from 3.5 million in 1990, sustained growth of approximately

Figure 1: Map of Puerto Rico Identifying the Location of Toll Facilities.

1% per annum. Across the same period, car ownership has risen from 1,460,000 to 2,248,500 vehicles [5] (a compound annual growth rate of 2.4%) and vehicle use – measured in terms of daily vehicle miles travelled – has increased by 3.7% per annum [6].

Taken together, these figures reveal that Puerto Rico has a car ownership per capita level around 0.58. This is considerably higher than the US average (0.48) [7] – in fact, only four states exceed the Puerto Rico figure (New Hampshire, Massachusetts, Connecticut and Ohio) – and international comparisons suggest that this represents one of the highest levels of car ownership of any country in the world [8]. Congestion levels on local roads bear testament to that fact.

TOLL ROADS IN PUERTO RICO

The first toll facility in Puerto Rico – the Juana Díaz ramp on PR52 – was opened in September 1971. This marked the beginning of a programme of tolling, the proceeds from which were used to accelerate the construction of key inter-urban expressways on the Island. Since then four tolled highways (PR52, PR22, PR53 and, just recently, PR20) and a tolled bridge have been constructed. The highways are operated and maintained by the Puerto Rico Highway and Transportation Authority (PRHTA). The Teodoro Moscoso Bridge is operated and maintained by a private company, Autopistas de Puerto Rico y Compañia SE, under a concession agreement with PRHTA. These facilities are summarised in Table 1. A map (Figure 1), identifies their location.

Tolls are collected at mainline plazas and ramp facilities on the network. More details about these facilities, including selected performance figures, are provided in Table 2.

Table 2 demonstrates the extent of toll road activity in Puerto Rico; more than 600 lane miles of toll road (most have a divided-4 or divided-6 configuration), over 200 toll lanes, some 800,000 transactions a day and a revenue stream exceeding $125m/year.

TOLL COLLECTION TECHNOLOGIES

PRHTA currently uses comparatively traditional toll collection methods at its plazas and ramps. Each toll lane is equipped with an automatic coin machine (ACM). In the 'manual' lanes, attendants provide change for drivers and deposit the toll in the ACM. In unattended lanes, drivers place the exact toll in the ACMs themselves. Each of the toll lanes is equipped with a gate to prevent violations. Analysis of vehicle flows by toll lane type shows that throughput at the attended lanes averages some 350 vehicles/hour and at the automatic coin machine (ACM) lanes rises to 550 – 600 vehicles/hour (Steer Davies Gleave, July 2000).

In recent years at some of its busiest toll plazas [9], PRHTA has successfully increased vehicle throughput by employing 'ushers' to speed the toll transaction process [10]. These ushers, stationed beside the unattended ACMs during peak hours, take the toll from drivers and time the placement of money into the ACM basket such that the gate remains permanently in the 'up' position. Additionally the ushers can make change if required and it has been observed that their presence encourages drivers to have the toll payment ready in advance of arriving at the plaza. Sustained throughput of around 800 vehicles/hour has been observed at ACM lanes with ushers.

Until recently, this presented PRHTA with an operational dilemma. The Authority was keen to explore ways in which throughput could be improved at its congested plazas, however early-generation electronic toll collection deployments (eg. 'crawl-through' with a gate in situ) achieved vehicle throughputs of between 850 and 1,300 vehicles/lane/hour [11],[12] – not much more than the usher-assisted existing system performance.

The more recent advent of highway-speed tolling technology and operations (achieving 1,800+ vehicles/lane/hour), however, prompted the Authority to review its position.

Table 1: Toll facilities in Puerto Rico.

Toll Facility	Facility Type	Operator	Route	Distance	Full Route Toll (auto)
PR52	Highway	PRHTA	San Juan – Ponce	60 miles	$2.40
PR22	Highway	PRHTA	San Juan – Arecibo	62 miles	$2.35
PR53	Highway	PRHTA	Ceiba – Yabucoa & Guayama – Salinas	24 miles	$1.55
Teodoro Moscow Bridge	Bridge	Autopistas de Puerto Rico	Across the San José Lagoon, San Juan	1.4 miles	$1.50
PR20	Highway	PRHTA	Guaynabo – San Juan	4.7 miles	$0.50

Source: PRHTA & Autopistas de Puerto Rico (2000)

ETC PROCUREMENT

From the outset, PRHTA was particularly keen to bring a global perspective to the toll challenges that it faced in Puerto Rico. The first task for the consultancy team was to undertake an international review of state-of-the-practice in terms of automated toll collection systems. This was conducted although our findings were tempered by the fact that only certain technologies could be deployed in Puerto Rico. For example, Puerto Rico – as a US territory – is governed by the Federal Communications Commission (FCC) which restricts the frequency range allocated to dedicated short range communications (DSRC) to 900 – 928MHz. Thus in-vehicle transponders available in other parts of the world that operate at 2.45GHz or 5.8GHz could not be employed in Puerto Rico or on the mainland US [13].

The results from our state-of-the-practice review started to define the parameters which PRHTA is using for the procurement process to bring ETC to Puerto Rico. At present (September 2000), Steer Davies Gleave is evaluating the bids from vendors with the assistance of The eTrans Group Inc., a US team of ETC experts. Contract award is scheduled for October 2000.

At the heart of our Request for Proposals (RFP) was a functional system specification that had been agreed with PRHTA. While writing and agreeing the system specification, we were required to address a number of key issues that had to be considered before the definition of the procurement process could be finalised. These topics form the basis of the rest of this article and are described here as 'issues for consideration'.

Table 2: Toll stations, transactions and revenue.

Toll Facility	Number of Toll Collection Facilities: Plazas	Ramps	Lanes	Average Daily Toll Transactions	Annual Revenue ($m)
PR52	5	4	73	292,500	$46.7
PR22	6	1	69	402,100	$57.9
PR53	5	0	42	95,300	$11.4
PR20	1	0	8	n/a(A)	n/a(A)
PRHTA Sub Total	**17**	**5**	**192**	**789,900**	**$116.0**
Teodoro Moscoso Bridge	1	0	10	24,700	$13.4
Islandwide Total	**18**	**5**	**202**	**814,600**	**$129.4**

Source: PRHTA & Autopistas de Puerto Rico (2000)

Note (A):The PR20 toll plaza was opened within the last two months and, as such, established performance figures are not yet available.

ETC: ISSUES FOR CONSIDERATION

The issues outlined below have been selected for inclusion in this article because (a) their consideration was fundamental in terms of defining the requirements for a local ETC system, and (b) they have a relevance beyond Puerto Rico. The order in which the issues are introduced does not infer a hierarchy of importance. The issues summarised in the following sections are:

- Technological issues;
- Legislative issues;
- The appropriate 'level' of violation enforcement;
- Customer support operations;
- Design issues;
- Interoperability issues;
- Technology applications beyond ETC;
- Making ETC a success.

At the end of the article key conclusions are drawn from our experiences.

Technological Issues

In theory, a number of technologies could be employed to identify the user of toll roads with the purpose of establishing some pre-paid or automatic payment mechanism. These range from low-tech solutions (eg. paper-based systems) to the use of technologies such as surface acoustic waves, bar codes and laser scanners and global positioning systems (GPS) allied to mobile communications. Early in our study, we settled on a radio-frequency (RF) solution and, as was described earlier, it was restricted to a specific frequency range (900 – 928MHz).

The RF solution offered a number of important attributes:

- It was mature technology with a proven track record;
- It offered the required speed and accuracy of read for a highway-speed application;
- The vendor community was sufficiently large to ensure competition during procurement;
- The vendor community was sufficiently experienced in terms of large-scale systems implementation.

Most importantly, the combination of the attributes listed above defined the RF solution as a progressive yet relatively risk-free strategy, an important political consideration for a procurement process which, with supply, installation, operation and maintenance commitments, will cost over $100m.

However within the RF solution, there were still decisions to be made. For example, there are four types of RF transponder. Type 1 is a read-only unit. Type 2 is read/write. Type 3 is yet more 'intelligent', incorporating integrated circuitry (a microprocessor) allowing for greater data transfer between the tag and readers, and a Type 4 transponder allows a Smartcard to be inserted in (and interfaced with) the tag.

From the point of view of highway-speed tolling, there is little to choose between the Type 1 and Type 2 units. There is no significant overall cost penalty associated with adoption of the Type 2 units, and the procuring agency retains the flexibility to use the 'write' functionality at a later stage if it wishes.

Type 3 tags have not been used extensively in tolling anywhere (in the US or elsewhere). These tags have been used typically as modems for communication with on-vehicle computers – eg. to fine tune the engine management system on long-haul trucks.

The Smartcard option [14], on the other hand, deserved considerable investigation, particularly as PRHTA (a highway and transit authority) was currently constructing the Tren Urbano rail system in San Juan and so the potential existed for the development of some integrated payment medium.

Smartcards are used in Europe and beyond (eg. Singapore – specifically for road pricing) but rather less so in the US, where their transportation applications tend to be limited to payment systems for transit (public transport) services. The ADEPT project trials in Europe demonstrated that a Type 4 tag could be used for real-time toll payment deductions at vehicle speeds over 100 miles per hour however the perceived drawback of Smartcards in highway applications is the Smartcard interface, the security requirements and the slow processor and its power requirements. In short, as with Type 3 tags, the additional functionality associated with this technology simply did not have a market and the additional costs could not be justified

After lengthy consideration, Smartcards were discounted for ETC in Puerto Rico on the following grounds:

- For tolling applications in general, the technology is still in its infancy. In the US, existing (primarily RF) technologies have benefitted from considerable investment and, as such, the pressure to move from a proven technology to new technologies is not strong;
- Cost: although the unit cost of Smartcards themselves is less than $5, the unit price of the interface (transponder) is still around $100. Furthermore preliminary quotations suggested that the system costs could be double those required to support RF technologies;

- The public demand for an integrated (transit/tolling) payment solution was likely to be low;
- The potential multi-application attributes of Smartcards (beyond transportation) were still restricted – and would probably remain so unless banks became more active advocates;
- The size of the vendor community was small and this would limit competition during procurement;
- The experience of the vendor community and toll road authorities was limited – and that limited experience was not good. An earlier deployment (in Orange County, California) met with significant public opposition. Patrons perceived no gain for the additional cost and inconvenience associated with this technology.

In terms of the RFP, we remain open to considering Smartcard-based tolling solutions in the future. For that reason, vendors replying to the RFP are required to map an upward migration path from their existing technologies to Smartcards if and when the Smartcard option becomes more attractive.

The second part of this article appears in next month's TEC

What is electronic toll collection?

Electronic Toll Collection (ETC) is a generic term for the application of various technologies designed to automate the traditional toll collection process of stop-and-pay. Drivers can pass toll collection points at various speeds, from 'crawl though' to highway-speed – depending upon the technologies deployed – and the toll is collected automatically (described later). Some open-highway systems with ETC have done away with toll booths and plazas altogether.

ETC literature typically describes these technologies in terms of their three main functional components: automatic vehicle identification (AVI), automatic vehicle classification (AVC) and violation (or video) enforcement systems (VES). Each of these components (or sub-systems) is summarised in the paragraphs below.

Table 4: Advantages of electronic toll collection

Beneficiary	Advantages
ETC Customers	Speeds transaction time and reduces journey delay.
	Improved convenience and comfort (no need to search for change, wind down the window etc.).
	Extends payment options (cash, credit card, debit card, cheque etc.).
	Commercial users no longer require cash or ticket from employer (open to abuse). Can also be extended to allow vehicle tracking.
	Receive monthly statement (no need for individual receipts).
	Improved safety (conventional toll collection can lead to accidents – typically rear-end collisions - by drivers distracted by the need to find change, choose lane etc.).
	Often linked to a discounted toll structure.
The Toll Authority	Increased toll processing throughput without new infrastructure.
	Reduced cost of toll collection (lower staffing costs).
	The authority receives payment in advance.
	Enhanced auditing capabilities.
	Enhanced toll enforcement.
	Improves public attitude to tolling [21].
	Minimises right-of-way requirements for new plazas.
	Allows for elaborate discount programmes.
	Can be employed for congestion management purposes (through variable – eg. peak period – pricing) and other applications (see Section 6.6).
The Environment	**Air quality**: Improved air quality (particularly at toll plazas and in high-emission departure zones).
	Noise: Reduced noise from vehicle acceleration in departure zones.
	Light: Reduced lighting spillover to adjacent communities.
	Water quality: Improved water quality (reduced contaminated runoff from plaza pavement).

Source: Compiled from various sources by the author

Automatic Vehicle Identification (AVI)

Despite what the title suggests, automatic vehicle identification does not identify a vehicle. Instead, it identifies a customer account and it is this account that is debited to pay the toll. The account is identified by the placement of a unique, customer-registered transponder or 'tag' on the inside of a vehicle's windscreen. This tag uses radio frequencies [15] to communicate with an antenna mounted at the toll collection point, thus alerting a reader attached to the antenna to its presence.

A variety of pre and post-payment arrangements exist. With the most commonly employed pre-payment schemes in the US, the customer deposits a balance in their account – say US$50, usually through credit card payment – and this balance is decremented each time a toll collection point is passed. An automatic replenishment scheme is employed to 'top up' the balance when a minimum threshold, such as US$10, is reached.

AUTOMATIC VEHICLE CLASSIFICATION (AVC)

For the purpose of calculating the appropriate toll to be charged, vehicles are usually divided into different classes and a graduated scale of tolls is employed – the toll rate schedule – to reflect the wear and tear (at least notionally) that different vehicle types cause to the pavement. In a manual system, subtle differences between vehicle types can be employed to derive highly disaggregated toll schedules. Occasionally, journey purpose or vehicle ownership information may also be used to derive the appropriate charge [16]. Such subtleties are cost-prohibitive to employ within current ETC systems.

Instead, automatic vehicle classification systems use sensors [17] to identify key vehicle attributes (such as number of axles, presence of dual tyres, length and/or height), thus placing the vehicle in an appropriate class for the purpose of calculating the correct toll charge.

With AVC, it is still possible to employ disaggregated and effective toll structures. By measuring three vehicle attributes, for example: number of axles, presence of dual tyres and vehicle weight, and using the results in combination, many vehicle types can be correctly identified automatically. Furthermore, correlations between attributes can be imaginatively employed to minimise an AVC system's sensor requirements. For example, a study by Vollmer Associates for the New York State Thruway Authority [18] found a strong correlation between two-axle vehicles measuring more than 7' 6' (2.3m) and vehicles with a maximum gross weight of over 7,000lbs (3,175kg). Light sensors were used to detect these 'over-height' vehicles (trucks) and distinguish them from lighter two-axle vehicles (cars).

Violation Enforcement Systems (VES)

The current system of toll collection employed in Puerto Rico was introduced earlier in this article – a conventional stop-and-pay system with gates to prevent toll violations. The Highway Authority's objective of increasing throughput by moving to a highway-speed toll system was also discussed. Clearly this necessitates the removal of toll gates and this increases the potential for non-payment violations by drivers without valid transponder-equipped vehicles to occur.

In response to this (and for some fully automatic ETC systems to be able to cater for pay-by-plate [19] customers) violation enforcement systems have been developed.

A violation enforcement system typically captures a digital or video image of the registration number (licence plate) of vehicles passing through ETC facilities without a valid AVI transponder (the 'trigger event'). The image is then processed either manually or employing optical character recognition (OCR) software [20] and is referenced against the state or national vehicle registration database to determine the vehicle's owner. A bill for the toll and administrative charges is then sent to his/her home address. Non-payment of this bill typically leads to recourse through the judicial system.

THE ADVANTAGES OF ETC

The potential advantages associated with the deployment of ETC technologies are summarised in Table 4 on the previous page. Note that not all of these will be achieved in every circumstance.

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The responsibility for any errors or omissions is, however, the author's own.**

The bibliography will be published with Part 2 in the December issue of TEC.

Notes:

1. The author, an Associate with Steer Davies Gleave, has managed their Caribbean Office in San Juan, Puerto Rico for the last five years. He can be contacted at sdgpr@caribe.net.

2. Puerto Rico Planning Board.

3. Encarta Online @ www.encarta.com.

4. Puerto Rico Planning Board.

5. FHWA Annual Highway Statistics –1997, Section VI, Table R-1.

6. Office of Highway Statistics, Puerto Rico Highway and Transportation Authority.

7. FHWA Annual Highway Statistics - 1997, Section I, Table MV-1.

8. World Road Statistics, 1998, International Road Federation.

9. Two toll plazas in Puerto Rico currently cater for over 100,000 vehicles a day: the Buchanan Toll Plaza on PR22 (165,000/day) and the Caguas Norte Toll Plaza on PR52 (130,000/day).

10. Other capacity enhancement initiatives taken by PRHTA include the use of reversible lanes at plazas (to take account of peak period directional traffic demand) and the conversion of some plazas to one-way tolling (thus enabling the plaza to be extended in the tolled direction).

11. Plaza Design (see bibliography), Table 7, p 46.

12. It should be pointed out, however, that safety concerns were commonly the key to determining in-lane speeds and that, even with these early ETC deployments, technology was not the key capacity-limiting factor.

13. The US DoT currently has a case pending with the FCC regarding allocation of the 5.8GHz frequency band, but it is not planned for ETC use in the US for the foreseeable future.

14. Smartcards have been considered at length by a number of toll authorities in the US (eg. Florida, for the Sunpass ETC project) but have been rejected. A type of Smartcard interface by AT&T was used on the first section of the Foothill Tollroad in California but motorists found them awkward and they were not useable anywhere else. In general, the US consumer has been very slow to take to Smartcards – hence there are few examples of widespread deployment (and toll authorities still unconvinced by this technology are not particularly keen to pioneer their introduction).

15. Radio frequency technology is most commonly adopted for ETC in the US. Other technologies employed use laser scanners and bar codes, or infrared frequencies. Some toll authorities are known to be currently exploring the use of GPS and mobile communications.

16. For example, taxis in Boston pay a higher toll than private cars, although they are the same generic 'type' of vehicle. Furthermore, in some areas, residents from particular communities enjoy preferential toll rates.

17. Sensors can include inductive loops or treadles, light beams or curtains, various scanning devices (such as ultrasonic, infrared, laser or video image scanners) and 'profilers' that assess the bulk or mass of a vehicle.

18. 1996 study by Vollmer Associates, subsequently incorporated in reports for the International Bridge, Tunnel and Turnpike Association (IBTTA).

19. Pay-by-plate: Some fully automated ETC systems (eg. Highway 407 in Toronto) use violation enforcement technologies as a mechanism for catering for bone fide infrequent users. It may not be practical nor desirable for such users to attain a transponder, however – with an eye on maximising revenue – the toll authority may wish to encourage their use of the road anyway. The ETC system detects the absence of a transponder, captures a video image of the licence plate and through the Department of Motor Vehicles registration records the vehicle owner is identified and a bill is sent to his/her home address.

20. At an IBTTA ETC Technology Workshop in Arlington, VA early in 1999, the percentage of licence plate images correctly identify by optical character recognition was reported to be 60–70%, with subsequent human intervention increasing that percentage significantly.

21. In 1988 the Urban Transportation Monitor conducted a survey of public attitudes to toll roads. 66% of respondents approved of their use. This figure increased to 85% in favour of toll roads if ETC technologies were deployed.