Pre-Class Tolling Systems. A Discussion Paper.

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Abstract

Abstract: This white paper outlines some of the issues related to Automatic Vehicle Classification (AVC) in tolling pre-class systems. It will address both the problems and possible ways of solving them. It is the authors contention that unless all factors affecting such a system are properly aired then a successful deployment is unlikely. This paper offers a technical solution whilst highlighting the issues which arise and how these can be resolved.

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1 Introduction

Most tolling systems in the world today employ post-class AVC avoiding the technical difficulties associated with pre-class. By its very nature pre-class AVC is significantly more complex and difficult to implement reliably than its post-class cousin. Great care must be taken in its design to ensure potential problems are minimised.

As a result of increasing adoption of electronic toll collection (ETC) and open road tolling (ORT), the travelling public is coming to expect a painless transition through toll plazas.

This white paper addresses the system issues and technical challenges involved in pre-class tolling. The technology does exist to provide an accurate and efficient pre-class system. Success will depend on a proper understanding of all the issues involved and the willingness of all parties to work together to achieve the best result.

Overall accuracy and reliability of pre-class tolling is dependent on the vehicle tracking sub-system, which is a part of the overall lane controller environment. Vehicle detection is a part of this sub-system; the vehicle tracking is provided by a separate module sitting between the vehicle detection and the lane controller.

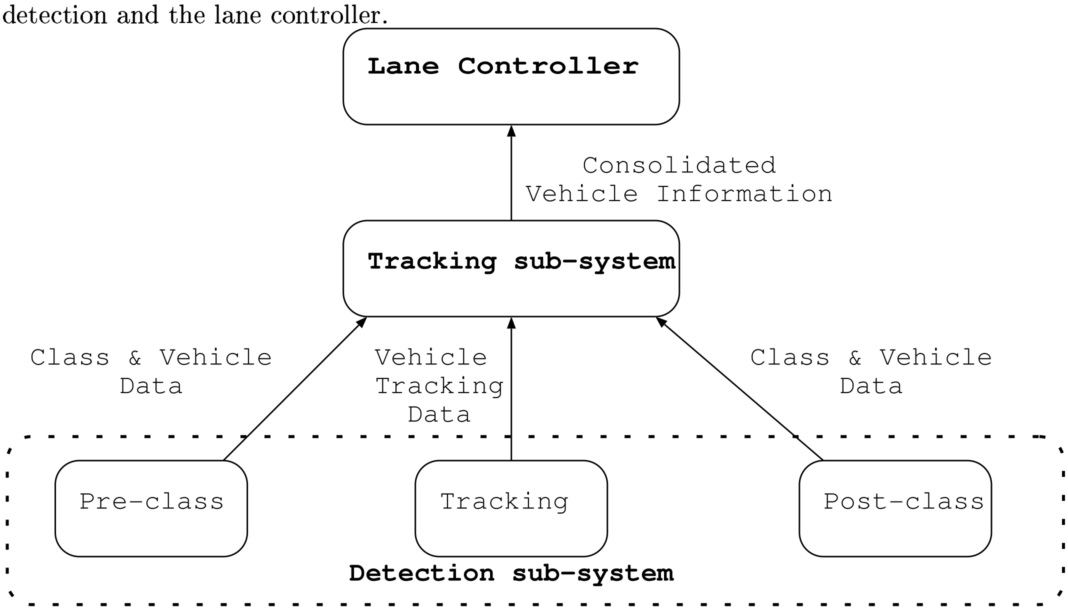


Figure 1: Conceptual Pre-Class System

A number of the issues and solutions raised in this paper may be more appropriate to overall business rules. They are raised here for consideration as part of a complete solution utilising pre-class tolling.

2 Summary

Whilst the technical solution will be employed in both attended (manned) and unattended (automatic) lanes, it is the latter which presents the greater challenge. Years of experience of engineering systems together with R&D effort specific to the tolling industry has enabled us to outline a system approach and potential solution to the problem of accurate and reliable pre-classification. We are certain that adoption of such systems is practical and can be a useful adjunct to normal RF tag based ETC and conventional tolling systems.

Whilst ETC and high speed ORT are the holy grail of the tolling industry few toll authorities enjoy the luxury of a green field environment. Many toll authorities have large existing client bases who may be 'cash only' customers, or have a significant proportion of occasional customers, particularly tourists. In these cases accurate and reliable pre-class based tolling offers two significant benefits:

1. improvement in customer service;
2. reduction in collection costs.

Unlike tag only based tolling, a pre-class system can provide these benefits without requiring all customers to have bank accounts or be locally resident and willing to obtain a tag.

Our belief is that for a pre-class project to succeed system issues have to be clearly identified, a realistic assessment made of the expected performance levels and proper ownership taken. A partnership of operator and vendor is most likely to succeed.

3 Requirement for a pre-class AVC system

There are two principle reasons for deploying pre-class AVC in toll systems:

1. to present vehicle class to a toll collector; or
2. to allow for variable toll rates in unattended toll lanes.

It is likely that the most effective pre-class system will consist of:

1. a pre-class classification array;
2. an intermediate array between the pre-class point and the payment point;
3. a classification array post the payment point, a post-class array.

Due to the nature of pre-class systems, the classification component must be situated so that vehicle classifications are available to the system (and hence the customer) as the driver approaches the payment point. The distance[1] between the classification component and the payment point must be sufficient to accommodate the longest vehicle. This means that a number of shorter vehicles will fit in the equivalent space. (See Figure in section 5.1). An important consequence of this is that any pre-class AVC will have to:

1. cope with stop/go traffic on a regular basis; and
2. account accurately for every one of those vehicles in order to present the correct tariff to each vehicle.

The requirement for vehicle classification and tracking on the approach to the plaza exists irrespective of whether the lane is attended or not. The only difference between an attended and unattended lane, and this is a crucial distinction, is the method by which the system can 'correct' for separation and classification errors. In an attended lane some interaction with the toll collector can be allowed for. In an unattended, fully automatic, lane the system has to correct itself, or a means must be provided for customers to register a disagreement with the toll presented, and to pay what they believe is correct. One could sympathise with a customer driving a car who is presented with a toll for a semi-trailer. The consequence of not providing a means to resolve the problem is:

1. an unhappy customer; and
2. delays to customers behind in the queue.

Neither of these outcomes is desirable and may lead to customers avoiding using the toll road in future. At an unattended payment point a clearly marked button would be necessary, labelled:

"Press if presented with incorrect toll."
"Pay correct toll for your vehicle."
"Video evidence will be collected to verify correct toll paid"
together with a tariff table.

Toll fee discrepancies would be dealt with initially by comparing the vehicle classification provided by the pre and post-class array. Those showing a discrepancy against the post-class array would be resolved using the VES image. Processing by exception helps to keep operating costs low.

4 Pre-class system issues

4.1 Requirements for Attended and Unattended Operation

1. High Accuracy: Accuracy can be improved by using a post class array for confirmation, although payment depends on pre-class.

[1] **This distance may typically be 75 to 80 feet (25 metres).**

2. Reliability: The system should have robust components and sensors, and complexity should be minimised
3. Simplicity: Vehicles should be constrained to lane at and downstream of the pre-class array to minimise irregular vehicle movements.
4. Self auditing: Auditing carried out by post classification array.

4.2 Requirements for Unattended Operation (desirable in attended lanes)

1. Ability to self correct quickly: In the event of errors or irregular vehicle movements the pre-class tracking system must be capable of detecting and correcting its own errors. Multiple arrays allow maximum chance to correct initial errors and to detect irregular movement.
2. Customer feedback: Provide means for customer to disagree with pre-class assessment. This would cause a VES image to be saved.
3. Simple and clear for customers to use.
4. Contextual transactions to enable resolution of unusual events: e.g. what the customer attempted to do, what succeeded, what went before and what came after. This resolution would be part of the back office operation.

4.3 Rarely Acknowledged Truths!

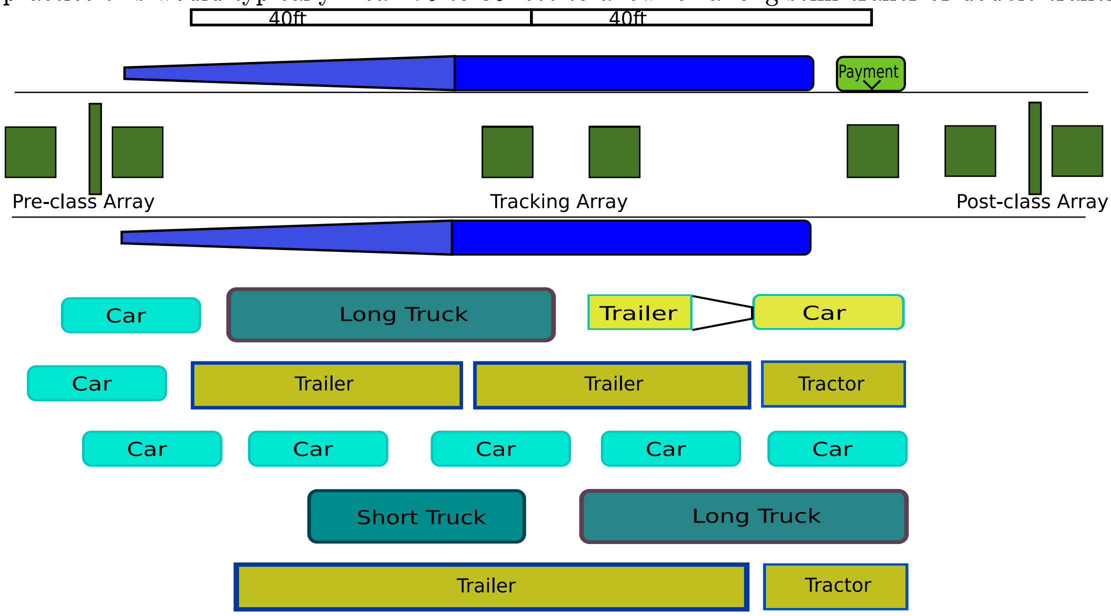
1. An AVC array on its own will not be 100% accurate, especially in a pre-class environment. It has to be expected that a pre-class array will be in "continuous" congestion.
2. Errors will occur both in separation and classification.
3. By far the most important and difficult error to deal with is the separation error, i.e. two vehicles joined or one vehicle split.
4. The tracking system will have to automatically take account of these errors and correct for them.
5. An intelligent use of available information, obtained from both pre- and post-class arrays must be made.
6. Voting between classification arrays in order to achieve an acceptable accuracy will only compound the problem; after all, which one is correct?
7. Unreliable operation will cause the system to gain a bad reputation.
8. A bad reputation will affect both operator and vendor(s).

5 Technology

5.1 Plaza requirements

In any pre-class system the vehicles will have to be separated into lanes and channelled at the classification point so that lane switching at or beyond this point is not possible. Whilst it may be possible to track vehicles between lanes beyond this point, the investment in extra equipment and development effort seems hard to justify when lateral separation is necessary in any case at the payment point.

The distance from the classification zone to the payment point depends on the allowed vehicle classes in each lane, and must allow for the maximum expected vehicle length plus a margin. In practice this would typically mean 70 to 80 feet to allow for a long semi-trailer or double trailer.



Vehicle Mixes and Possible Lane Layout

Figure 2: Schematic Pre-Classification

It is possible to segregate trucks and cars so that they are required to queue in different lanes. However this is likely to require more lanes than plaza capacity allows. This is because the exact vehicle mix will never be predictable. The required capacity for each separate segregated class must be allowed for. Since it is inevitable that vehicles will, on occasion, be in the incorrect segregated lane, such an approach may be of limited use.

A pragmatic solution leading to efficient use of the available plaza space and equipment would be to equip all lanes with the same technology and classification capability. This offers full usability of all lanes by all vehicles.

There are two main cases of plaza construction to be considered:

- new build, and
- retro-fit to an existing facility.

Clearly it is desirable to have a 'one solution fits all' if at all practical. Retro-fit inevitably places greater constraints on system design than new build. The choice of AVC and tracking technology plays a significant role.

Pre-class tolling requires an extension of the lane islands out beyond the pre classification point. In a new build situation the plaza can be designed to provide facilities at the pre classification point for a variety of vehicle separation technologies:

- above ground - light curtain or overhead scanner;
- in ground - loops.

In a retro-fit situation the addition of the required infrastructure to protect above ground sensors may not be feasible due to space and/or financial constraints.

In both cases the costs associated with extension of lane islands, suitable to support above ground detection and separation, to the pre-classification point may well be prohibitive. The lane island extensions for in ground detection and separation are much more modest; they only have to keep the vehicles in lane rather than provide accomodation and protection for above ground sensors.

5.2 AVC technology

The detection technology must be capable of achieving the following three tasks:

1. separate and classify vehicles;
2. track vehicles once they have been classified;
3. provide information to assist the tracking system to determine errors and correct them.

From the discussion above, it is clearly evident that an all in ground solution is desirable. This would obviate any need to protect conventional light separators or provide overhead structure.

Idris(R)[2] - an inductive loop only AVC developed by Diamond Consulting Services Ltd meets the requires for detection, classification and provision of tracking information. This technology relies entirely upon in ground inductive loops for its vehicle detection, separation and classification. It can classify both according to number of axles and vehicle type, for example it can differentiate

[2] Idris(R) is the trade mark of Diamond Consulting Services Ltd and incorporates Patented technology under one or more of the following patents: EP0879457, USA 6345228, 6337640 & 937741. Patent Applications Pending in other Countries.

a bus from a similarly sized truck. Using loops addresses the requirement for reliability noted in section 4.1, since loops are a long lasting and robust sensor technology, particularly when installed in high quality pavement.

Idris is a versatile technology which both acts as an AVC, and provides tracking and the additional vehicle identification information required to ensure a consistently accurate and reliable system. Synchronisation between the classification point and payment point must be maintained. One or more additional separation loop pairs could be placed in the region between classification array and payment point at low incremental cost in order to ensure extremely high separation accuracies. The Idris algorithms processing the data from these arrays can be configured to provide additional information about the separation decisions they are making. This assists the upper level systems to determine when errors are being made in the primary separation system, ensuring the correct decisions are made prior to each vehicle presenting at the payment point.

6 Idris as the Detection Solution

6.1 Idris Technology

It is anticipated that any Idris system used in a pre-class system will be implemented by an experienced Idris Technology Partner or a system integrator with Idris experience.

Specifically the Idris technology provides:

- accurate vehicle detection to include separation and classification both pre and post payment;
- the means to track vehicles through the toll lane from pre-classification through payment to post classification;
- the ability to have a user defined class table which can be a mixture of axles and vehicle type, for example buses;
- a classification array sufficiently upstream of the payment point to be able to display the correct fare due when the vehicle presents itself at the payment point;
- detection, classification and separation from stop/go (0 MPH) to over 100 MPH;
- triggers to VES for violation enforcement, available in both digital (contact closure) and as messages to external systems responsible for triggering, as required. To achieve the level of system accuracy required it is expected that a post-class array would be required and that this would be the same technology as the pre-class array, namely Idris;
- human readable outputs. Idris can display a text per vehicle record for every vehicle;
- a network interface on which all information is available. This interface is available to processes running on the same CPU as Idris as well as to other systems connected on a LAN;

- all below ground sensors. Idris uses only inductive loops for classification, including axles, and separation. Idris only detects vehicles, and therefore does not require to discriminate vehicles from artifacts in the lane;
- the ability to operate in high speed ORT lanes as well as barrier lanes. Idris was designed as a multi-lane system and handles straddling vehicles and vehicles travelling in the wrong direction in an ORT environment;
- a high mean time between failure. Typically loop detectors have MTBF's in the range of 50,000 to 100,000 hours. Well installed loops in good pavement last the life of the pavement;
- operation in all weather. The operation of Idris is not affected by adverse weather in any way.

Idris technology is capable of providing all the Agency's vehicle detection and classification needs. It has a proven track record in all types of lane, barrier, unattended remote and high speed ORT.

6.2 System Issues

6.2.1 Accuracy

Basic detection in a pre-classification detection array is not going to be as accurate as a post class array. On a busy plaza a pre-class detection array is likely to be working in a congested environment for most of the day. In contrast, a post-class array is likely for the most part to be free flowing unless there is a downstream blockage. It is recommended therefore that a post-class array is used as a component of the system for final transaction classification. It will also assist in the self correction of pre-class errors.

Accuracy will not be determined by a single component, rather it will be a result of a number of cooperating sub-systems. The output of Idris and the application of the Idris data is only a part of the solution.

System accuracy will depend on:

- Idris detection.
- System ability to detect and correct initial classification and separation errors.
- Plaza construction.
- Overall vehicle mix.
- Competent and intelligent integration skills.

It is recommended that where pre- and post-class system show a different classification, and where the customer has paid the correct toll for the lower of the two classifications, that the transaction be accepted. Any loss of revenue in such cases will be small, and the cost of investigating them is likely to vastly outweigh any revenue recovered.

6.2.2 Hardware and Software Requirements

Idris is a software product and is licensed on a per lane, per function basis.

Idris requires inductive loops, loop detectors and a 32bit or higher CPU. The loop detectors have to be Idris qualified and are available from several alternative vendors. The current CPU used in tolling environments is a Pentium class CPU of 200MHz speed or higher.

Idris runs under a POSIX style operating system and is currently deployed under Linux or QNX 4. Both operating systems are equal in their ability to provide the environment under which Idris can run.

6.2.3 Reliability and Life Expectancy

Correctly installed loops, the only sensor proposed in this solution, will last the life of the pavement into which they are installed. Loops are a highly reliable sensor and Idris systems installed in 1999 are providing the same level of accuracy today with no system or configuration changes.

6.2.4 Maintenance

The most likely source of failure in an Idris system is a loop joint or damage to the loop detector from a lightning strike. One is fixed by re-jointing and the other avoided, except in extreme cases, by appropriate lightning barriers.

6.2.5 Existing Post Classification

It is expected that a post-class array will be required to achieve the levels of accuracy and reliability expected. In an Idris environment the most effective solution would be to install Idris as the post class array.

7 Conclusion

The adoption of a pre-class AVC and vehicle tracking system can meet a toll agencies requirements. The technology exists and a suitable system can be designed and implemented. The whole can be greater than the sum of its constituent parts.

Idris is only one component in this system, albeit a vital one. It is expected that a tracking and error correcting sub-system will sit between the Idris algorithms and the lane controller. This equally vital role will rely on key information from Idris and may well feed back information to Idris to enable Idris to make better decisions.

It is expected that the tracking and error correcting sub-system would be provided by one of DCS's Technology Partners.