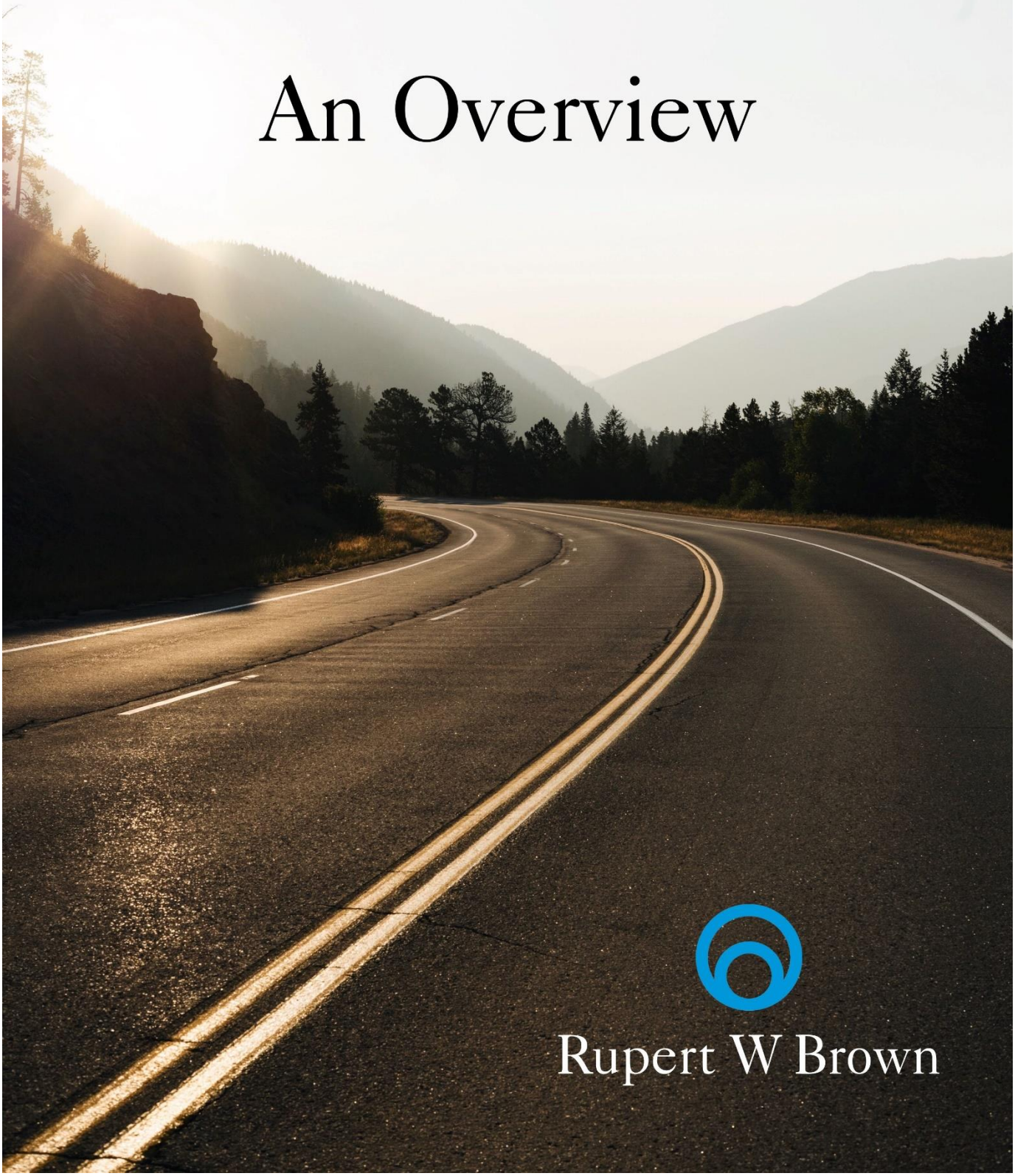
Multilane Free-Flow Tolling Systems

An Overview



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Tolling Considerations

Your own personal experience of tolling systems will vary depending on where you live. If you regularly commute by car into Sydney, Australia, paying tolls is probably part of everyday life. It is very hard to move around Sydney and not pay a toll. Conversely, if you live in rural England, you would spend most of your life blissfully toll free.

Cars are a very important part of modern life. They provide people with independence of movement, a sense of freedom and a powerful form of personal expression. We spend a lot of money buying cars, and then more filling them with fuel, and getting them serviced, insured and cleaned. The assumption that every car driver makes is that there will always be roads for them to drive on. For a long time, most roads have been provided by Governments "for free" although there is a significant history of turnpikes and toll gates around the world.

One point of view argues that good road infrastructure drives economic growth. Building roads creates jobs during construction and subsequently in maintenance and repair activities. Roads enable industry and the movement of goods. They facilitate trade. The opposing view is that new roads, rather than alleviate traffic congestion, actually make things worse by generating more traffic and thus more pollution. They take up real estate. They are dangerous. People die on roads all the time, everywhere in the world – more than 1.2 million *every year* - and roads cost a lot of tax money.

So what is to be done? Our societies couldn't do without them. At the same time there is a powerful argument that says "Why should my tax money go towards a road I'm never going to use?" Why should somebody living in Horsham (Victoria, Australia) contribute tax money to a motorway in Melbourne, or somebody living in Norwich (England) pay to keep the traffic moving in London?

So Governments are increasingly accepting the need to build toll roads on the basis that tolls are the only way to fund and thus get a road built, with the bonus that only those people actually using the road have to pay for it. The "user pays" principle - it can be a workable compromise. Then there is another school of thought that says "tolls are taxes" and do not take into account a person's ability to pay. A Billionaire in a Bentley pays the same as a Pauper in a clapped-out Corolla. But isn't that the same as the public transport system? Ahh yes, but there is such a thing as a concession card! Toll roads are politically sensitive, and as such they have to be ready to face the full gamut of cross-bench scrutiny.

Because of this Governments have to approach the building of new toll roads with a degree of caution. Many voters do perceive tolls as just another tax, and politicians that raise taxes don't always do well at elections. So in planning a new toll road, a Government will think about "safeguards" and "considerations" such as:

"Whatever we do, tolls have to be 100% accurate. People don't like paying, but when they do we can't have them being charged incorrect amounts" – this thinking leads to the development of a whole range of financial Key Performance Indicators (KPI) for the toll road operator.

"We've got to make it easy for people to pay their tolls" – which drives the need for a whole range of payment options including via retail outlets, a website, with cash through a service centre and over the phone.

"We want to change traffic patterns. We want more people travelling at off-peak times to ease congestion" – which leads to the need for toll rates that vary depending on the time of day and the day of the week.

"Some people drive little cars. They take up less space and do less damage to the road when compared to a huge truck" – this thinking leads to the need for toll rates that vary depending on the class of vehicle a person is driving.

"We can't toll ambulances. We can't charge the ambulance service for trying to save somebody's life" – this results in the creation of a special class of exempt vehicles, for which tolls will not apply. Typically this includes public transport buses.

"It's going to be hard for Taxi drivers to work out how much they should add to their fare to cover the tolls they incur" – this thinking leads to the creation of special rates for some classes of vehicle e.g. charging taxis a flat fee regardless of distance travelled.

"In time we will end up with more than one toll road, but we don't want users having to deal with multiple operators and multiple accounts" – and so the whole concept of interoperable tolling systems is created, where a customer with one account can travel on any toll road.

"Some people will only use the road once or twice a year. We have to make it easy for them" – this thinking leads to the development of casual user toll products like a single trip pass, or a book of trip vouchers.

"You have to be firm. If people use the road and don't pay we see it in the same light as shoplifting or public transport fare evasion. You have to go after them for money" – this leads to the need for some kind of enforcement system, some kind of legal process that allows the road operator to recover money.

"The whole thing has got to be easy to understand" – OK – "*and*",

"*You have to keep the cost of collecting toll revenue as low as possible*" – Right, I think we get the message. It's going to be a little more complicated than simply charging people and collecting the money.

All of these considerations, and the form and configuration of the road itself, create requirements that drive the detail of the tolling system design.

Tolling System Overview

The aim of this overview is to orientate ourselves with the components and functions of a tolling system. I'm presenting an MLFF tolling system architecture model here which I think represents the "state of the art" as we know it today. The experts will probably argue about whether this is correct till the cows come home, but we have to start somewhere. Figure 1 shows the main system components in this MLFF tolling system.

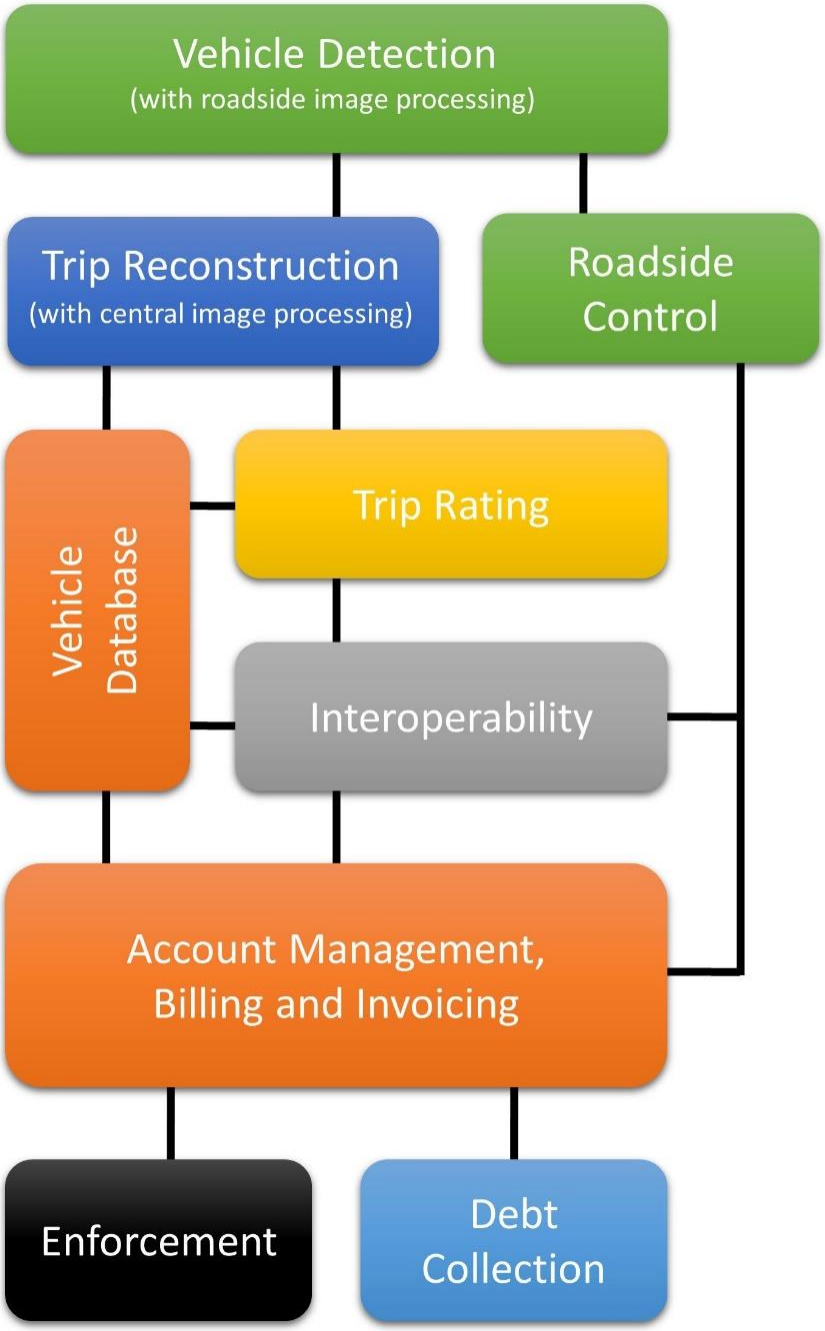

Figure 1 – Main system components in an MLFF tolling system.

Figure 2 then takes these components and puts them in the context of their physical locations.

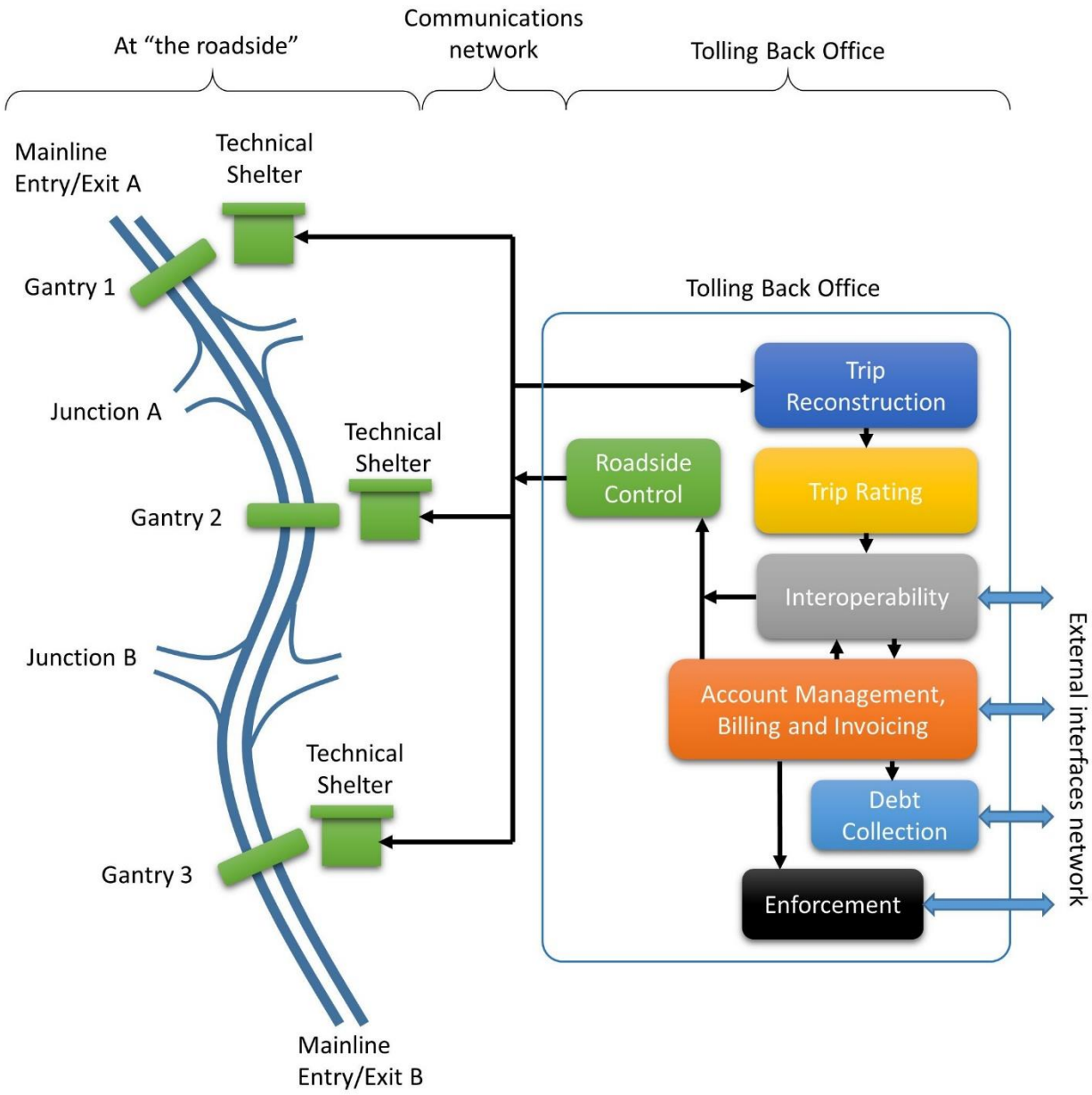

Figure 2 – System components of an MLFF tolling system in the context of their physical locations.

Vehicle Detection

The Vehicle Detection component – often referred to as "the roadside" - covers all the equipment and software necessary to detect vehicles using the road. Vehicle detection includes, but is not limited to items such as:

- On-board Units (OBU), usually referred to as tags. Tags are carried by the vehicles using the road. These tags can use a variety of technologies including Radio Frequency Identification (RFID), Dedicated Short Range Communication (DSRC) and infra-red.
- A gantry or similar structure next to or spanning the road upon which are mounted the vehicle detection sensors. The structure is intended to position the sensors in the best place for vehicle detection, while keeping them out of the way of vehicles and pedestrians.
- The sensors themselves which include tag readers, cameras, vehicle detection systems, vehicle classification systems and illuminators (lights).
- Computer equipment and software which processes and sends on the data from the sensors. This equipment resides in some form of technical shelter – building or cabinet – located close to or inside the gantry structure. Often these technical shelters have air conditioning and some form of back-up power, be that an uninterruptable power supply (UPS) or a standby generator.
- A communications network that allows processed sensor data to be passed back to the tolling back office.
- A power supply to power all the equipment in the technical shelter and on the gantry.

Figure 3 below shows a typical two gantry configuration – looking at it from the side, with vehicles travelling from the left of the page to the right. The structure to the left is the rear gantry which is configured to take images of the vehicle's rear licence plate. The structure to the right is the front gantry which is configured to scan vehicles for classification purposes, take images of the front licence plate and perform tag communications.

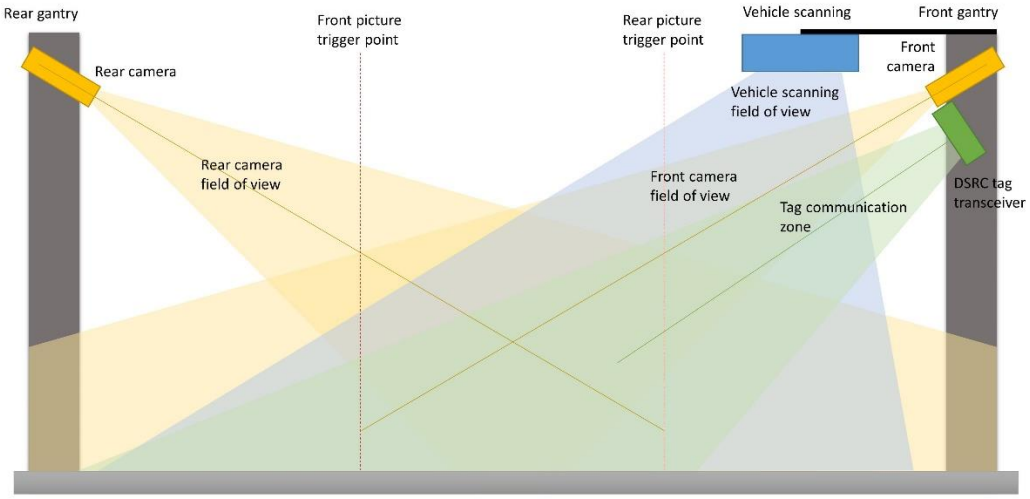

Figure 3 – Typical two gantry configuration of roadside vehicle detection equipment.

As vehicles pass within range of the detection equipment, its role is to send Tag and Vehicle Passages (detection events), and images, back to the Trip Reconstruction component. A Tag Passage captures the unique identification number of the tag in the vehicle. A Vehicle Passage captures the size and position of the vehicle on the road and also the licence plate characters and

numbers, the string. It is able to do this because the cameras contain optical character recognition (OCR) engines which, in most cases, can read the licence plate string from the images.

These acronyms DSRC and RFID - from Wikipedia:

DSRC - Dedicated short-range communications - one-way or two-way short-range to medium-range wireless communication channels specifically designed for automotive use and a corresponding set of protocols and standards.

RFID - Radio-frequency identification - the wireless use of electromagnetic fields to transfer data, for the purposes of automatically identifying and tracking tags attached to objects. The tags contain electronically stored information. Some tags are powered by energy from the interrogating radio waves and act as a passive transponder. Other types, have a local power source such as a battery and may operate at tens of meters from the reader.

For the system to work tags and tag readers both have to be compliant to the same standards.

Roadside Control

Roadside Control is the control of the behaviour of the roadside equipment. Roadside Control includes the ability to:

- Turn all the equipment on a gantry on or off. Roads do need to be closed for maintenance and if that maintenance happens to be under or near a gantry, the last thing you want is to pick up all the maintenance vehicle traffic. You turn the gantry off.
- Change parameter values. The roadside equipment is usually quite parameter driven, and from time to time the value of parameters need to be changed. One example of this is the set of parameters that define the three dimensional spaces used to classify vehicles into certain classes.
- Synchronise time. As will be seen below, making sure all the gantries are synchronised in time is very important for accurate trip reconstruction.
- Control lists. These lists instruct the roadside equipment to take actions when certain conditions prevail. For example, the roadside equipment is able to communicate with tags and make them "beep". One list is made up of all the tag identifiers which belong to tolling accounts that are in a "low balance" state. The roadside knows that it has to make any tag on that list beep "one plus two" times, when it passes through the gantry, as opposed to the usual one beep.

Trip Reconstruction

I use the words "Trip Reconstruction" simply because our toll road customer has used our road and we're trying to reconstruct their trip based on the Tag and Vehicle Passages we received from the roadside. The Trip Reconstruction component has two principal tasks:

1. Identify *exactly* what was detected and when, to create a transaction with a *unique identifier*,
2. To group transactions with the same *unique identifier* and that conform to a set of reconstruction business rules, so that they can be formed into a *trip*.

In the two statements above there are some important words:

Exactly – the Trip Reconstruction process has to be quite precise in determining what was detected and the time it was detected. It is very important that the system is able to correctly

determine *unique identifiers*. Errors at this stage can lead to incorrect charges being applied to customers, which can reduce our tolling revenue through re-work and tolls having to be written off.

Unique identifier – in the context of toll roads, a unique identifier is:

- a licence plate string, the state or country of registration and sometimes the vehicle class, or
- the identification number of the tag carried in the vehicle, or
- both.

Hopefully by the time we get to Trip Reconstruction we have some licence plate string and registration data provided by the roadside. In my architecture, image processing within Trip Reconstruction is the application of business rules to determine if the data we have from the roadside is accurate enough to use without additional image processing and/or manual intervention i.e. getting a human involved to look at images. Trip Reconstruction can use the data as is, pass the images through a second OCR engine to get additional data, or hand it over to a person. In the vast majority of cases, the combined image processing capability (IPC) of the tolling system should be able to automatically confirm the licence plate string and registration details.

Over the years, Tag Passages at the roadside have proven themselves to be consistently reliable. It used to be the case that if a good tag read was picked up by the roadside, then that tag identification number would become the principal unique identifier for the purposes of trip reconstruction. As will be seen later, issues with vehicle class mean that we do really need to identify the actual vehicle travelling on the road, which means getting that licence plate string. The tag identification number is by no means redundant. It remains a very useful piece of data for trip reconstruction purposes.

Trip – It may sound odd, but determining what constitutes a trip can be quite complex. Figure 4 below is a representation of a simple toll road. It has two mainline entry and exit points, two junctions and three tolling gantries.

Imagine a vehicle enters the road at Mainline B and passes under Gantry 3. Gantry 3 creates detection events. The vehicle then exits the road at Junction B, and the driver spends five minutes getting a coffee, before re-joining the road at Junction B and driving through Gantries 2 and 1. Does that constitute one trip? The vehicle did actually leave the road, but as far as the tolling system is concerned, there are three sets of detection events, one for each gantry. The system has no way of knowing the vehicle left the road unless it understands the concept that a trip should take a certain amount of *time*. It follows that the definition of a trip obviously involves road topology, but also a sense of time as well, and thus the need to be precise about detection time. These considerations lead to the creation of trip reconstruction business rules.

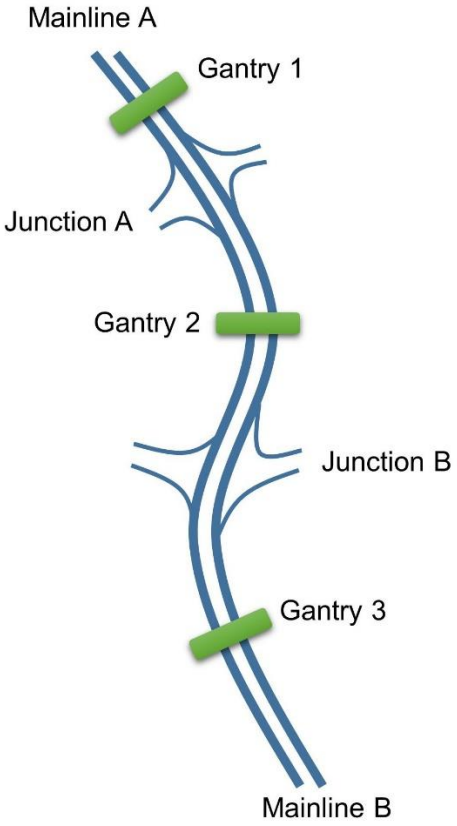

Figure 4 – A simple toll road topology

Trip Rating

Trip rating takes each trip and calculates the appropriate toll. Tolls can be calculated in a variety of ways, but the factors involved in calculating a toll usually include:

- The distance, or the number of toll zones (passages under gantries) travelled by the vehicle,
- The class of the vehicle, be that a motorcycle, car, light commercial vehicle or heavy commercial vehicle – or some other classification scheme,
- A variable toll value, determined by an algorithm, intended to maintain a minimum speed or volume of traffic along the road.

Adjustments may also be applied, such as:

- Discounts for off-peak travel, or premiums for peak time travel,
- A trip cap, which is a maximum amount for any given trip,
- Discounts for short trips, or trips along certain sections of the road.

Interoperability

Interoperability between toll road operators allows a customer to have one tolling account and travel, without the need for other arrangements, on all the toll roads whose operators have signed up to an interoperability agreement. For this to work, interoperability requires the exchange of information between all the toll road operators covered by the agreement.

Firstly, interoperability relies upon the existence and the sharing of details around *arrangements to pay*. An arrangement to pay is said to exist when a toll road customer has opened a valid tolling account with a toll road operator, or bought some kind of casual tolling product such as a trip pass.

This arrangement to pay data can be manifest in the form of *blacklists* and *whitelists*. The easiest way to explain this is to go straight to an example.

- In Australia, all tags are considered valid **unless** they appear on the tag blacklist. They are put on the tag blacklist when there **is no** valid arrangement to pay for that tag.
- Licence plate strings are only considered valid if they are **on** a licence plate whitelist. They are put on the whitelist when there **is** a valid arrangement to pay for that licence plate.

This works because the tag identification number contains details of the toll road operator who issued the tag. If the toll road operator is a member of the interoperability agreement, all their tags are assumed valid by default, unless they're not i.e. on the blacklist. A licence plate has to be on a whitelist so that a toll road operator knows who has the arrangement to pay with that licence plate. The plate on its own can't carry that information.

Every day in Australia, all the toll road operators prepare their own tag blacklists, licence plate whitelists and another list that shows the association between tags and licence plates on their customer accounts. All these lists are shared between all the toll road operators, who then in turn compile master lists. These master lists sit at the heart of the interoperability process.

As trips are created on a toll road, the unique identifier associated with the trip is compared to the master lists and is sorted along the following lines:

- This is my customer travelling on my road – assign that trip to the customer's account.
- This is somebody else's customer (another toll road operator) travelling on my road – assign that trip to the other toll road operator's interoperability account. These other operators are called Interoperable Partners.
- This is recognised as a vehicle that is not required to pay tolls, an exempt vehicle – assign the trip to the exempt vehicle account.
- We see that this vehicle has a licence plate which is not on a whitelist, and/or has a tag which is on a blacklist – assign this trip as a *No Arrangement to Pay* (NATP) trip.

In addition some trips may become disputed. This usually occurs when one operator believes a customer has a valid arrangement to pay and the operator that owns the customer account disagrees.

At the end of the day, all the trips on your road made by customers belonging to other toll road operators are sent off to those toll roads. Similarly, all the trips made by your customers travelling on other toll roads are sent to you. Your tolling system then has to apply those trips to your customers' accounts.

The Australian system works well every day, even though there is a significant amount of duplicated effort between toll road operators. The key point is that it makes it very easy for customers – one tolling account gives them access to all the toll roads in Australia. Figure 5 below summarises this process.

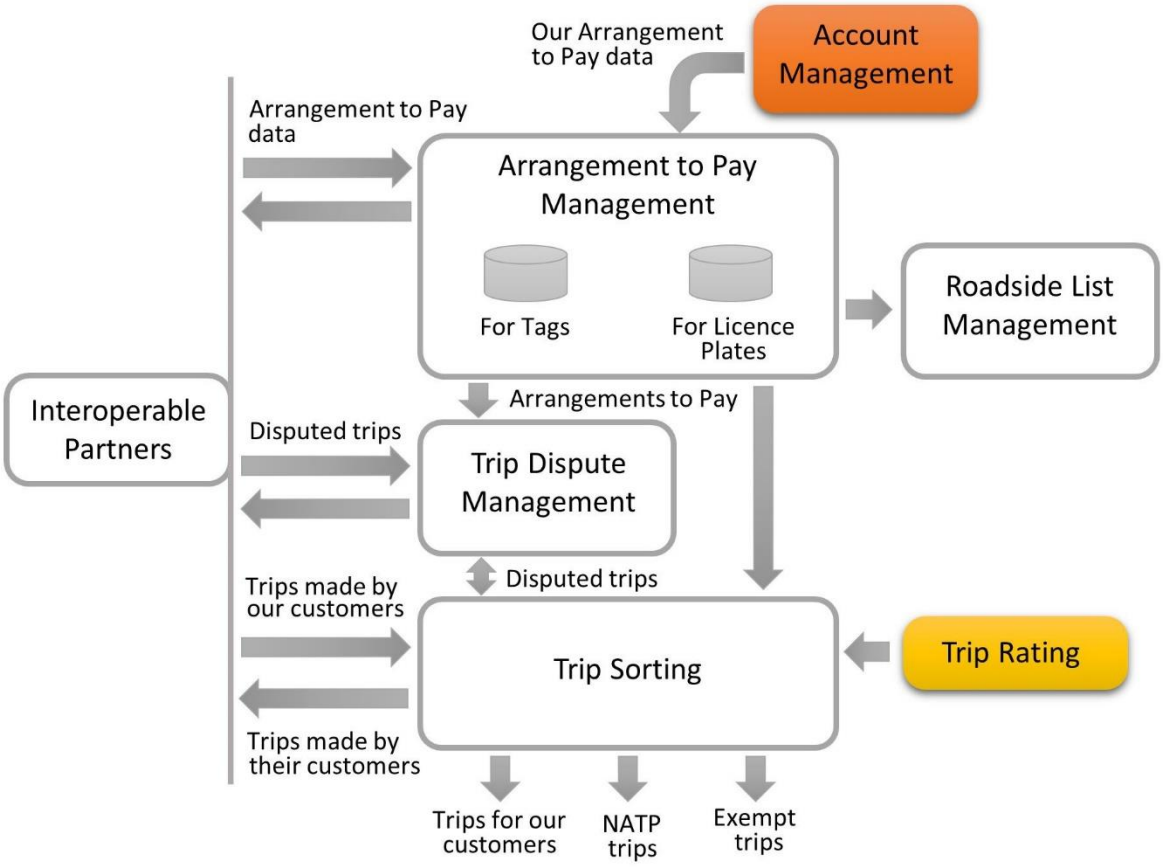

Figure 5 – The basic (Australian) interoperability process

In figure 5 there is a box marked "Roadside List Management". This covers the production of lists that are sent back to the roadside equipment via the Roadside Control component. Lists contain details of tags whose associated account is either in a low balance state or suspended and thus blacklisted. In Victoria, Australia, the roadside instructs the tag to beep once for a valid arrangement to pay, one plus two beeps for an associated account in low balance, and four beeps for a blacklisted tag which means the associated account has been suspended, or the tag is marked as lost, stolen or destroyed. This beep mechanism provides direct and immediate feedback to customers on the state of their account.

Account management, billing and invoicing

The account management, billing and invoicing component is at the heart of the tolling system back office. Its two critical functions are to manage the accounts of the toll road's customers, along with their personal and contact details, and to manage those NATP trips made by people who have used the road but have no valid arrangement to pay. Principal functions include:

- Maintenance of "toll products". A toll product defines the type of account that a customer uses to create their arrangement to pay with a toll operator. Toll products are typically:
    - Pre-paid – where a customer deposits an amount of money in their account, and the balance reduces over time as they use the road and incur tolls. Once an account low balance threshold is reached, the customer is prompted to manually

top-up the account with more money, or an automatic top-up occurs through a direct debit arrangement.
    - Post-paid – where all the tolls incurred by a customer are itemised on an invoice and sent to the customer once a month. The customer pays the invoice.
    - Tag based – where the customer is issued with a tag to place in their vehicle.
    - Video based – where the customer relies on the toll operator reading their licence plate string to correctly apportion the toll. In practice there is little difference between a video and a tag based account save for the fact that video trips incur an additional image processing fee, and there is usually some kind of financial deposit required before a tag is issued.
    - Trip pass – a trip pass represents an arrangement to pay, albeit for a single trip on the road. It is usually a video based, fixed price product that can be purchased up to three days after the date of travel. It is aimed at the very infrequent road user.
- Customer Management. The management of customers' details including their account balance, trip and payment records, contact details and links to vehicle and tag details.
- Channels Management. Inbound and outbound customer contacts, management of enquiries and complaints, and the generation of notifications to customers such as low balance alerts.
- Billing and Invoicing. All the processes involved in creating statements and invoices and mailing them to customers be that via e-mail or regular post.
- The creation of NATP trips. An NATP trip usually results in the creation of an NATP account which treats the value of the NATP trip as a debt. The debt then has to be managed through the enforcement and debt collection processes.
- Tag logistics. The management of tags including their acceptance from the supplier, the allocation to and returns from customers, and their repair or destruction.
- Interfaces. The tolling system requires many external interfaces in order to function. These include:
    - A bank interface to handle the vital financial transactions. Increasingly tolling systems are making use of bank tokenisation services to reduce their exposure to the security requirements imposed by the Payment Cards Industry (PCI).
    - An interface to the local vehicle registration authority. This interface allows the toll operator to use a licence plate string to look up the name and address of a vehicle owner in order to recover the cost of NATP trips.
    - Alternative payment channels such as post offices or payment services in convenience stores.
    - Customer self-service channels such as web sites, mobile apps and telephone based interactive voice systems.
    - An interface to the toll road operator's corporate financial system to keep track of the money.

Enforcement

Enforcement systems vary greatly around the world. Following is the process toll road operators are allowed to use in Victoria, Australia. Customers are given three days to pay for a NATP trip. The idea is you can travel, and then settle up by buying a trip pass or opening an account. If after those three days no attempt has been made to pay for an NATP trip, then the enforcement process begins. Using the interface to the local vehicle registration authority, the toll operator will attempt to find the registered owner of the vehicle that made the trip based on the recorded

licence plate string. The owner will then be sent an NATP Invoice. The NAPT Invoice will be for an amount equal to the tolls plus an administration fee. If the owner does not pay within a certain timeframe, a second NATP Invoice will be issued. This second NATP Invoice includes the original toll amount, but with an increased administration fee. If the owner does not pay this NATP Invoice, the matter becomes a civil offence and passes out of the hands of the toll operator and into the realm of the local enforcement authority. The owner becomes subject to a fine, and if the fine is not paid, the whole matter may end up in court.

The enforcement route is a necessary but painful and time consuming process for everybody concerned. Experience shows that the sooner you are able to communicate with your customers and tell them the situation they are in, the better the outcome.

Some jurisdictions place restrictions on what can be enforced. In some cases, even though a vehicle has been spotted on a road four times in one day, the authority will only accept that one offence has been committed and will therefore only enforce one trip.

Debt collection

The enforcement process cannot be relied upon to recover all the money owed due to NATP trips. Those trips that cannot be enforced still represent money owed to the toll road operator. Operators will use a variety of techniques to try and recover this debt, including the outsourcing of collection services to professional debt recovery organisations.

Vehicle Database

Lastly we come to the Vehicle Database. This is probably not a feature you will see explicitly addressed in most current tolling systems, but I'm using it as a place holder to remind us that we must be constantly thinking about future-proofing these systems where possible. Every tolling system has some capability for storing vehicle details, and the relationship between Vehicles and Tags which is fine, but it hardly represents the future we are confronted with. Within a couple of decades the majority of our cars will be wirelessly connected, discrete DSRC or RFID tags will probably be redundant and we may not even need to attach licence plates.

The Vehicle Database is there is make us think about what we really need to know in order to be able to accurately and efficiently charge our customers for the use of the infrastructure. Right now it is a licence plate, a state of registration, a tag ID number, a vehicle class, maybe even a photo or two of the vehicle and the signature of the licence plate. In the future will it be a Vehicle Identification Number (VIN), an IP or MAC address and a LIDAR-derived 3D model from which we determine vehicle class?

The Vehicle Database is there to help us keep track of our customers' vehicles, whatever form they take moving into the future. Its purpose is to make robust the link between what we actually observe on the road to the people that pay the money for using the road.