WORKING PAPER

The Congestion Question

Could road pricing improve Auckland's traffic?

Workstream 2

Technical assessment

August 2019

Working draft vB

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1 Glossary

Term/Abbreviation	Definition/Description
ANPR	Automatic Number Plate Recognition. Video decoding technology that uses static or video images of vehicles to identify their licence plate and convert it into alphanumeric text. Term used interchangeably with ALPR (Automatic Licence Plate Recognition).
AT	Auckland Transport
Congestion charging	Charging vehicles for use of specific roads during specific times and days, in order to reduce the severity and duration of congestion on the network.
DSRC	Dedicated Short Range Communications. Also known as tag and beacon road charging, whereby a small battery powered device is installed in a vehicle to enable identification in a toll system. Not used in New Zealand.
GNSS	Global Navigation Satellite System. A generic term for such systems which includes GPS, GALILEO and GLONASS
HTTPS	Hypertext Transfer Protocol Secure (HTTPS) is an extension of HTTP used to communicate securely across the Internet.
IP	Internet Protocol
JSON	JavaScript Object Notation (JSON) is a standard format of human readable text used to pass data between computers.
MVR	Motor Vehicle Register. The NZTA managed electronic register of all vehicles and their registered owners. Computer systems can interface with the MVR electronically using the CDI (Common Data Interface).
NZTA	New Zealand Transport Agency
OCR	Optical Character Recognition
RUC	Road User Charge. The New Zealand weight/distance road charging system applicable to heavy vehicles and light diesel vehicles.
VMS	Video Management Software
VPN	A virtual private network (VPN) extends a private network across a public network by adding a security layer between two end points.
WIM	Weigh In Motion technology. Utilises on road sensors to automatically weigh passing vehicles without the need for them to stop
WOF/COF	Warrant of Fitness / Certificate of Fitness

2 Executive summary

2.1 Introduction

The purpose of this technical assessment is to provide advice on the preferred technology solution that would underpin a possible congestion pricing scheme in Auckland and to evaluate whether this would necessitate the development and implementation of a new end-to-end solution or whether it could build upon available infrastructure and systems. Existing technology solutions deployed by AT and NZTA were evaluated for applicability and recommendations are made on reusability, expandability, scalability and security.

The methodology adopted for this technical assessment followed: a high-level reference design to baseline scope; meetings with key stakeholders; technical information gathering on existing AT and NZTA systems; assessment of information based on expert review and finally the publishing of the main findings.

2.2 Main findings

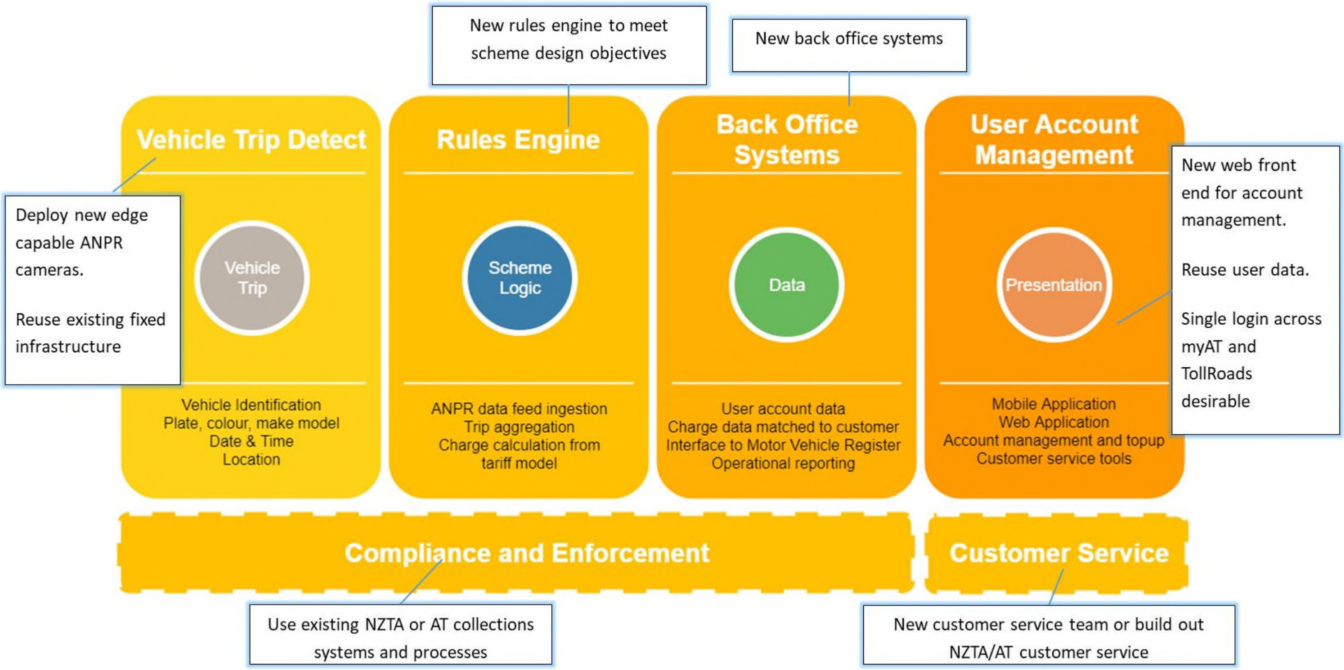
The following new system areas are required:

- Deployment of a new ANPR camera network capable of on board ANPR decoding.
- Congestion charging rules engine to receive ANPR data and operationalise the tariff model.
- Congestion charging back office systems including interface to the MVR and operational reporting into: customer service, technical operations, finance and enforcement.
- Friendly and easy to use mobile/web app for customer account management.

The existing areas within AT/NZTA that can be reused:

- Existing camera infrastructure such as mounting poles, power, networking and roadside cabinets.
- Depending on camera location, a small number of the existing AT cameras could be utilised. This would require a connector from AT VMS system to be developed.
- ATOC asset management team for the monitoring, maintenance and tuning of cameras.
- AT new camera installation process that utilises ProVision team to ensure best mounting and configuration of cameras.
- Existing relationships with networking, CCTV and civil works suppliers.
- AT or NZTA collections systems and processes.
- Potentially some reuse of NZTA toll road web application.
- Customer service teams within NZTA or AT could be expanded to support congestion scheme.
- Existing asset management teams within ATOC should be utilised for the monitoring of network and camera performance.

FIGURE 1: SUMMARY OF MAIN FINDINGS



2.3 Other recommendations

Use of single sign-on credentials across myAT, NZTA toll roads and the Congestion Scheme would be desirable. Login should consist of an email address and password. To share all login credentials across the three systems it would make sense to reuse an existing login system such as RealMe and migrate user databases from toll roads and myAT.

If there is a decision to proceed with congestion charging, it is recommended that consideration is given to the Congestion Charging entity adopting the NZTA toll road system when the operational contract with Kapsch expires. If done prior to rolling out the congestion scheme it provides the opportunity to test and harden the technology in a side-by-side environment. Consolidating the technology used provides the opportunity for significant efficiency improvements, cost savings and scalability advantages.

Exports from the congestion charging system could provide:

- Time of day traffic flow, speed and volume reporting.
- Vehicles of interest query (Police).
- Video feeds into ATOC VMS for incident and traffic monitoring.

3 Introduction

Central Government and Auckland Council have been working together for several years on a project called 'The Congestion Question' (TCQ). The project has its origins in the 2016 Auckland Transport Alignment Project (ATAP) where one of the outcomes was to look further at the role that demand management could play in the future of Auckland's transport system.

Following the completion of a comprehensive short-list evaluation exercise and the provision of advice to decision-makers, the next phase of the TCQ project is to refine the City Centre Cordon and Strategic Corridors options as they were recommended to be taken forward for further detailed investigation and analysis.

The purpose of the technical assessment is to provide advice on the preferred technology solution that would underpin the two preferred options and to evaluate whether the introduction of a congestion pricing scheme would necessitate the development and implementation of a new end-to-end solution or whether it could build upon available infrastructure and systems. This has significant implications for estimated scheme costs, the required timeline for delivery and overall project risks.

The report is based on a review of the available technologies, and also presents a summary from meetings with technical experts from NZTA and AT and their vendors. The existing technology solutions deployed by the two agencies are evaluated for applicability and recommendations made on reusability, expandability, scalability and security. The topics covered by this paper include:

1. Introduction
2. Methodology
3. Technical Overview
4. ANPR Background
5. Vehicle Detection Technologies
6. Rules Engine
7. Back-Office Systems
8. User Account Management
9. Compliance and Enforcement

Key systems reviewed within AT included: Thales HOP card ticketing system; myAT portal; MicroFocus VMS platform; Special Lane Enforcement Systems; DCA Pinforce Citywide Parking System; AT road camera network; Infor Pathway management system.

The systems reviewed within NZTA included: toll roads system; Weigh Right System; NZTA road camera network.

4 Methodology

4.1 Overview

The methodology adopted for this technical assessment consisted of:

1. High level reference design to baseline scope of the technical assessment
2. Meetings with key stakeholders to gain overview of technical environment
3. Technical information gathering on existing AT and NZTA systems
4. Assessment of information based on expert review
5. Report summarising key findings

4.2 Agency contacts

TABLE 1: AGENCY CONTACTS

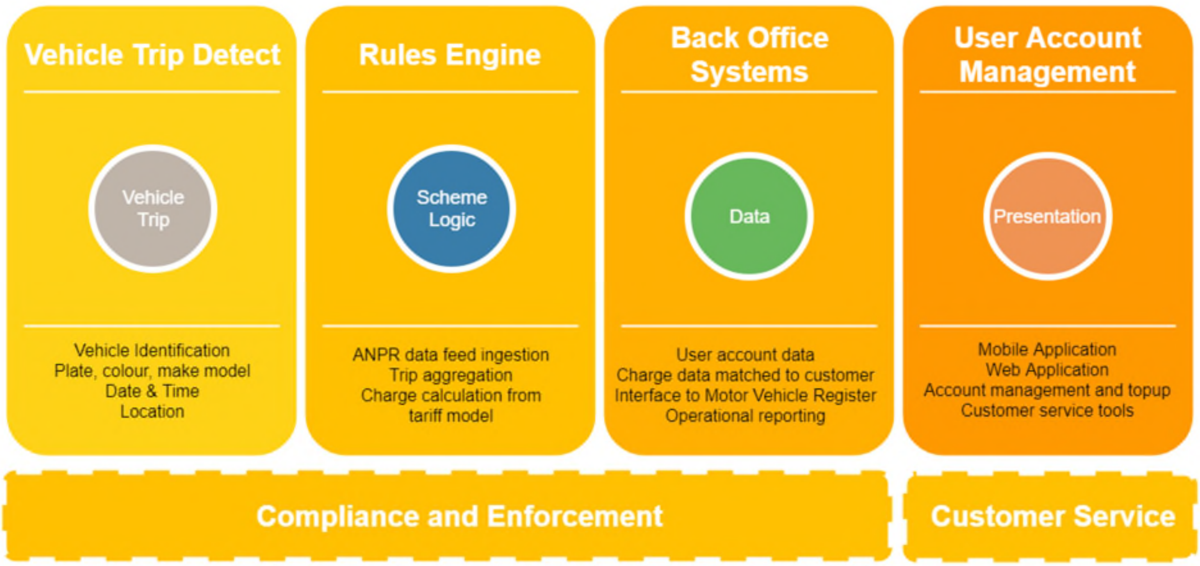
Agency	Area	Key Attendees
AT	Technology Leadership	Roger Jones (EGM Technology) Christine Perrins (Strategic Transport Governance)
AT	PropellerHead - Technology Partner	Andrew Weston (Director)
AT	Digital & Technology Delivery	Chris Creighton (Group Manager– AT) Ginny Nayler (ITS Programme Manager - AT)
AT / NZTA	SecuroGroup – Independent CCTV Consultancy	Scott Bain – (GM) Chris Wiggins (Director of Engineering)
AT	Microfocus – Technology Supplier (VMS)	Matthew Buchanan (Sales Director, IDOL Software – APAC) David Valentine -(VP Product Strategy)
AT	VMS - ProVision	Derek Zhang (Tech lead Pro Vision team)
AT / NZTA	Fusion Networks - Networking	Andrew Gurr – (Managing Director) Paul Demain – (Senior Manager IS Services)
NZTA	Connected Journey Solutions	Edwin Ng (Senior Manager – Integration – Connected Journey Solutions)
AT	Parking / Bus Lane Compliance	Garry Brown – Parking Compliance Area Manager CBD
NZTA	Weigh Right	Alena Douba – NZTA Technical Project Manager Edwin Ng – NZTA Senior Manager – Integration Phil Bingley – NZTA Solution Architect - Weigh Right
NZTA	Toll Roads	Robyn Elston – NZTA Senior Manager Design: Customer Services. Operations Edwin Ng – NZTA Senior Manager – Integration
NZTA	Toll Roads	Laksh Chinthapalli / Product Manager - Financial

5 Technical overview

5.1 Key functional elements

For the purposes of this technology review the system is divided into four key technology areas required to deliver a successful congestion charging scheme and two operational functions.

FIGURE 2: HIGH LEVEL TECHNICAL OVERVIEW



1. Vehicle trip detection encompasses the technology that is used to identify all vehicle trips within the chargeable area.
2. The charging scheme rules engine is the implementation of a logical set of rules that processes high volume vehicle trip data and applies the scheme tariff model to allocate appropriate vehicle trip charges.
3. The back office systems include all the data collection, aggregation, administration and operational reporting functions of the scheme.
4. User account management includes the presentation of user account information for users to manage their accounts, review trips and pay charges.

This report evaluates various options for successful deployment within each of these areas.

5.2 Technology selection for vehicle detection

Research undertaken for TCQ Steering Group on technology options in relation to vehicle detection suitable for Auckland found that: [1]

- ANPR technology has lowered in cost and become much more reliable since previous Auckland investigations into congestion pricing.
- ANPR technology is already proven in New Zealand for tolling, and can be readily applied for congestion pricing.
- ANPR is essential for the enforcement of any urban road pricing system.
- Advances in ANPR reliability have rendered DSRC obsolete for new urban road pricing systems.
- GNSS systems are technically feasible for full network road pricing, but not proven in operation. Singapore is looking to pioneer this application in an urban congestion pricing context from 2020 but will retain its roadside infrastructure network to support compliance and enforcement.
- Development of a GNSS solution would take considerably more time and expense than an ANPR solution, because: [2]
  - ANPR is required in any case for enforcement, and
  - GNSS requires over a million on-board units to be developed and supplied to Auckland road users incurring costs associated with installation, maintenance and inventory management.
- Smartphones do not provide an urban road pricing system solution in themselves, but can provide a user-friendly channel for payment and account management.
- ANPR technology offers the fastest deployment and lowest cost for a demonstration or pilot, and initial urban road pricing system.

ANPR offers a robust and effective solution without the need for road users to fit invasive hardware within their vehicles. All vehicle detection and identification can be done remotely using fixed roadside cameras and existing number plate registration and enforcement systems. Internationally ANPR is considered the most cost effective technology to meet desired road charging objectives. The only occasions where alternative technologies have been considered are in jurisdictions where licence plate quality is low or the vehicle register is questionable.

ANPR cameras are required for the enforcement of any congestion scheme and so it is logical to utilise these same cameras and back-end systems for vehicle trip detection and charging. A scheme utilising ANPR minimises development cost and risk considerably, whilst still meeting the objectives of TCQ. This first step does not preclude the opportunity to expand the system in the future by adding GNSS technology as wider public education and acceptance grows. This is in line with the approach taken internationally by Singapore who has been operating and incrementally modernising their charging scheme since 1975.

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[1] *Review of International Pricing Schemes, Previous Reports and Technologies for Demand Management*, D'Artagnan Consulting, (2017)

[2] *GNSS Technology Assessment*, TCQ Working Group Paper (July 2019).

6 ANPR background

6.1 Introduction

The foundation of a successful congestion charging scheme is the accurate and reliable detection and identification of all vehicles that travel within the charging zone. This section provides some background on this key technology element that underpins a congestion charging scheme. This information is required to form a view on the technology solution appropriate to the Auckland scheme.

6.2 How ANPR works

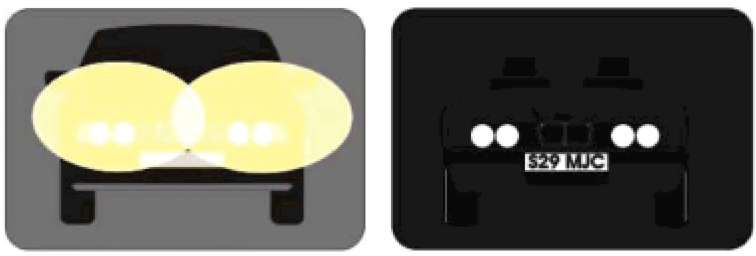
ANPR works through the use of roadside mounted cameras that continuously capture images of all passing vehicles. Images of the licence plates are then processed using optical character recognition (OCR) software and converted to machine readable text. This is similar to the technology used by document scanning software to convert document images into text documents.

From November 1986 all NZ plates are made out of aluminium with black embossed characters (numbers and letters) against a white retro-reflective background. This was done to make the plates easier to read and this applies to both humans and computers. Plates prior to 1986 are becoming increasingly rare due to the age of the vehicle fleet but these can be identified by white characters on a black background. Both styles of plate can be identified through ANPR.

FIGURE 3: NZ LICENCE PLATES (PRE AND POST 1986)

Specialised cameras may be used that have built in hardware that automatically adjusts and tunes the camera for optimal ANPR capturing. These cameras will typically include illuminators which are used to shine IR light at licence plates which due to their retro-reflective properties, makes the images brighter even under very low light situations or when vehicle headlights are on. Retro-reflective surfaces are covered in tiny hemispheres which cause light to be reflected back to the source. This is the same technology used in safety clothing and reflective signs. No matter from which direction the light is directed, it always reflects back and makes them very visible. Without the use of illuminators the accuracy of reads will be reduced during low light conditions.

FIGURE 4: EXAMPLE OF LOW LIGHT ANPR WITHOUT (LEFT) AND WITH (RIGHT) IR ILLUMINATOR



Internet Protocol (IP) cameras that send digital video feeds over public or private networks are a rapidly growing market and so there are hundreds, if not thousands of camera vendors to choose from. Vendor comparison and price analysis was out of scope for this report however it is fair to say there is a large variety to choose from with costs ranging from $1000 - $20,000 with higher-end cameras claiming to be able to perform better ANPR processing and support multi-lane detection from a single camera. Mutli-lane detection can result in a slightly lower read rate and so normally a single camera per lane is used. Additional direction cameras can also be added for both front and rear plate reads. This would increase the chance of an accurate plate read on vehicles that have an obscured plate. The number of cameras required at each detection point depends on scheme accuracy requirements as well as the number of opportunities for detection within the charging zone. Careful system design is necessary to optimise cost, accuracy and complexity trade-offs.

FIGURE 5: GENERIC LOWER COST CCTV CAMERAS

FIGURE 6: SPECIALISED ANPR CAMERAS WITH ON BOARD ANPR PROCESSING CAPABILITY AND BUILT IN ILLUMINATORS

6.3 Enforcement

Licence plates are used in NZ to identify all vehicles used on public roads. NZ law already has provision that all vehicles used on public roads must be fitted with a compliant unmodified registration plate. This is enforced through the vehicle registration process, WOF/COF system and by Police. NZTA issues all plates and manages the Motor Vehicle Register (MVR). This register keeps a record of all vehicle owners. Licence plates coupled with the MVR makes for the easy visual identification of a vehicle and linking of that vehicle to the registered vehicle owner. It is a well proven system with decades of refinement and reliable usage.

By using ANPR camera technology over the top of this existing system it is possible to perform plate identification quickly and autonomously. The decoded licence plate can then be used to search the MVR for the registered owner. This facilitates the automated association of a vehicle to a registered owner and enables the easy allocation of charges to a road user. ANPR technology is already utilised exclusively for identifying vehicles that travel on NZ toll roads[3]. In the unusual event that ANPR does not fully read all characters of the licence plate it is possible for vehicle make, model and colour to be identified from the photo. Make, model and colour are also recorded in the MVR and can supplement a partial licence plate read to search for the matching vehicle.

Licence plate compliance in NZ is very high due to the highly visible nature of plates and the penalties associated for failure to display a valid plate. Penalties of up to $5000[4] exist for displaying a non-approved plate or something that could be mistaken for a plate. NZ licence plate enforcement also benefits from standardisation across the entire country with no need to support international plates or even plate variety due to different issuing states like in Australia or USA. The existing legal and compliance framework for licence plates in NZ makes ANPR technology ideally suited for the enforcement of any congestion charging scheme. To implement any alternative technology for scheme enforcement would require a complete ground up approach to the motor vehicle registration and certification processes which would come at an enormous cost and significantly increase delivery timeframes. For these reasons, ANPR is the only technology considered suitable for automating compliance and enforcement of any congestion charging scheme.

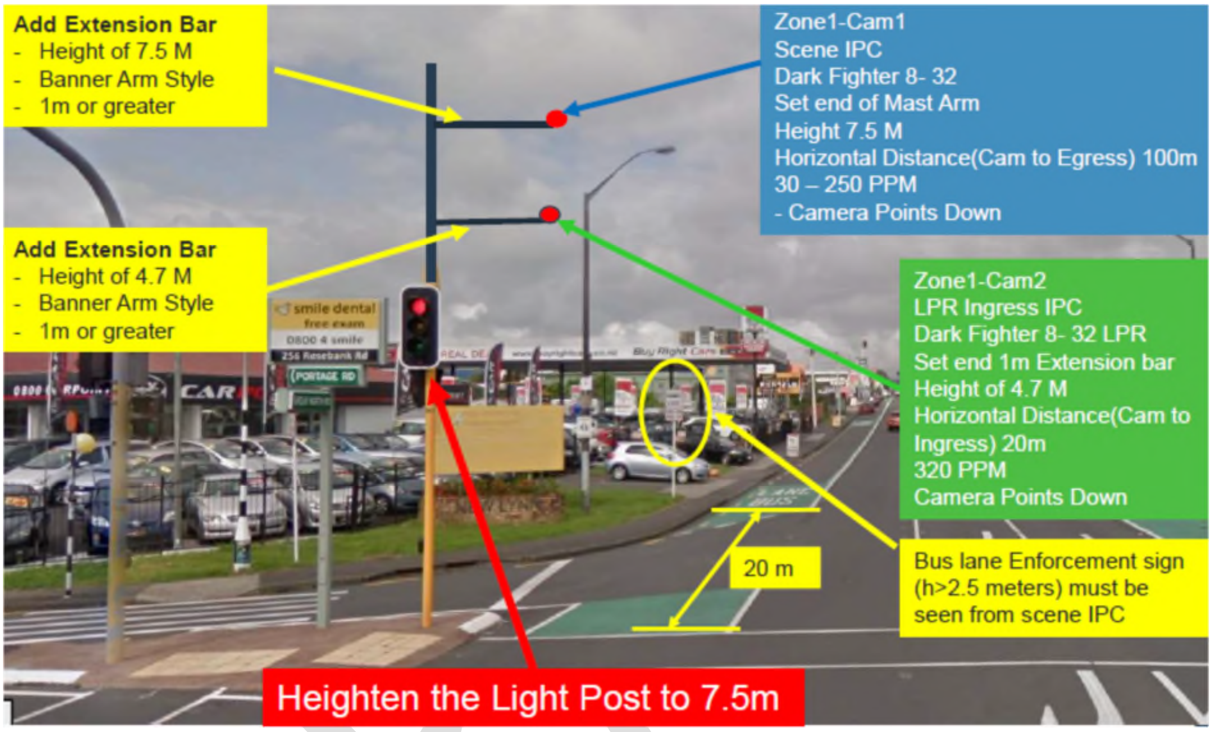
[3] https://www.nzta.govt.nz/roads-and-rail/toll-roads/toll-road-information/how-electronic-tolling-works/

[4] NZ Land Transport (Motor Vehicle Registration and Licensing) Regulations Schedule 6

6.4 Camera installation

Much of the cost of deploying new cameras is not the cost of the camera itself but the civil work costs to provide the poles, power and networking. Civil works required for a brand new camera installation can easily exceed $50,000. This is excluding the costs of a traffic management plan, if required.

FIGURE 7: EXAMPLE OF WORKS REQUIRED FOR NEW CAMERA INSTALLATION AT TRAFFIC LIGHT CONTROLLED INTERSECTION



6.5 Roadside cabinets and network security

At all traffic light controlled intersections there are roadside cabinets which house the traffic light controllers and networking equipment. Across Auckland there are over 875 traffic light controlled intersections. At all these sites there will be a level of network connectivity already provisioned. In many cases the cabinets can be quite full and so limited space is available for additional equipment. Physical security within the cabinet should not be assumed as all contractors have the generic keys to open all cabinets.

FIGURE 8: EXAMPLE OF ROADSIDE TRAFFIC LIGHT CABINETS

Depending on the existing hardware available at the cabinet, the minimum addition into the cabinet will be a network switch to connect multiple cameras into the network. Uninterruptable Power Supplies could also be considered to provide operation or at minimum a graceful shutdown of systems in case of a power failure.

6.6 Video management software (VMS)

Video management software is a server based software package used to collect video from cameras for storage, viewing and processing. There is normally an interface to access live and previously recorded video. Modern VMS systems usually incorporate additional image processing tools to perform things such as motion detection, facial recognition, traffic direction, traffic speed, alarm notifications and most applicable for congestion charging, licence plate recognition. VMS systems require a high level of networking, server processing and storage resources to operate. VMS is worth consideration for performing the ANPR within a congestion scheme particularly if lower cost cameras were chosen that were not capable of ANPR processing at the roadside.

6.7 Network requirements for camera network

There are three steps to correctly identifying a vehicle registration plate to link with a road user: Vehicle detection, Licence Plate Recognition (LPR) and Automated Number Plate Recognition (ANPR). LPR and ANPR are sometimes used interchangeably although it is worth making the distinction between detecting the licence plate within an image and decoding the numbers and letters on that licence plate. Modern trends are to perform ANPR on local hardware at roadside to avoid the need for transmitting high bandwidth video streams. This is being made easier by the ever reducing costs of high performance dedicated hardware such as Graphics Processing Units (GPU). Most camera vendors are now including this capability into a range of their cameras. There are now also open source projects such as OpenALPR which can be used to integrate ANPR easily into low cost hardware. It is not necessary to have an ANPR camera if video stream processing is done off-camera although the capturing of high quality images is paramount regardless of the approach taken. This is best achieved using cameras that are specifically designed for recording licence plates (ANPR cameras). These cameras will dynamically adjust their image settings as light and scene settings change. Only so much work can be done post-processing images so it is paramount to capture images with the best settings possible.

Accuracy is improved by using a well mounted camera with a high resolution and high frame rate video setting. As discussed previously, illuminators should also be used to maximise reads in low light conditions. Minimum video settings for 90%+ read accuracy are 1920x1080 (resolution), 25 frames per second (fps) with no compression.

The distributed roadside camera network must be connected back to the central charge processing servers. The bandwidth requirements for the network depend primarily on whether video decoding is done roadside or on central servers. The network requirements are considered for the two options in the following sections.

6.7.1 Network requirements for roadside ANPR (edge)

If ANPR processing is performed at the roadside (often referred to as edge ANPR because the ANPR processing is done at the edge of the network) then it is only necessary to collect a small thumbnail photo for reference, a high definition scene photo in the case of a legal challenge and lastly some metadata that includes the location, date, time and the decoded licence plate. Optionally the vehicle make, model and colour could be sent in this data packet as well. This metadata is typically transmitted in JSON format and uses very little data. An example of data sent is shown in Figure 9.

Figure 9: Example of small JSON metadata packet sent from camera


```json
{
   "error" : false,
   "epoch_time" : 1522978197756,
   "results" : [
      {
         "processing_time_ms" : 68.9315719604492,
         "vehicle" : {
            "body_type" : [
               {
                  "name" : "sedan",
                  "confidence" : 89.6389389038086
               },
            ],
            "year" : [
               {
                  "confidence" : 47.3032341003418,
                  "name" : "2000-2004"
               },
            ],
            "model" : [
               {
                  "name" : "corolla",
                  "confidence" : 22.9741859436035
               },
            ],
            "make" : [
               {
                  "confidence" : 32.4275550842285,
                  "name" : "toyota"
               },
            ],
            "color" : [
               {
                  "name" : "blue",
                  "confidence" : 15.9568424224854
               }
            ],
         },
         "plate" : "627WWI",
         "confidence" : 94.9990844726562
      }
   ],
}
```


The total data package size for each vehicle capture is approximately 150kb. This breakdown is shown in Table 2.

Table 2: Edge processed ANPR data package

Data	Size
Thumbnail photo	10kb
Scene photo	130kb
Metatdata	10kb
Total data package	**~150kb**

If we assume a maximum theoretical vehicle throughput of 2000 vehicles an hour per lane this would create a maximum of 2000 data packages per hour per lane. The maximum data connectivity for real-time processing would be 0.67mbps. *(2000 vehicles per hour x 150kB = 300MB / hr = 0.67Mb / sec).*

This requirement is well below fibre, DSL and even 3G mobile data speeds. This means that if camera based ANPR is used, even mobile data transmission is viable and it would be possible to avoid the need for fixed network infrastructure. Since real-time processing is not necessary and cameras can support a level of buffering as well as the fact that traffic volumes are typically much lower, a more likely bandwidth requirement is <0.5mbps.

The low bandwidth requirements of edge based ANPR processing means there is less demand loaded onto the existing network infrastructure, supporting future expansion and utilisation for other purposes. Mobile network support also enables cameras to be installed where no network backbone is present.

6.7.2 Video streaming network requirements

If ANPR video processing is performed at the back office then network infrastructure requirements are much greater. This is because the complete video stream of all cameras must be continuously transmitted for vehicle identification and licence plate processing. There are four key factors that influence the video stream bandwidth requirements:

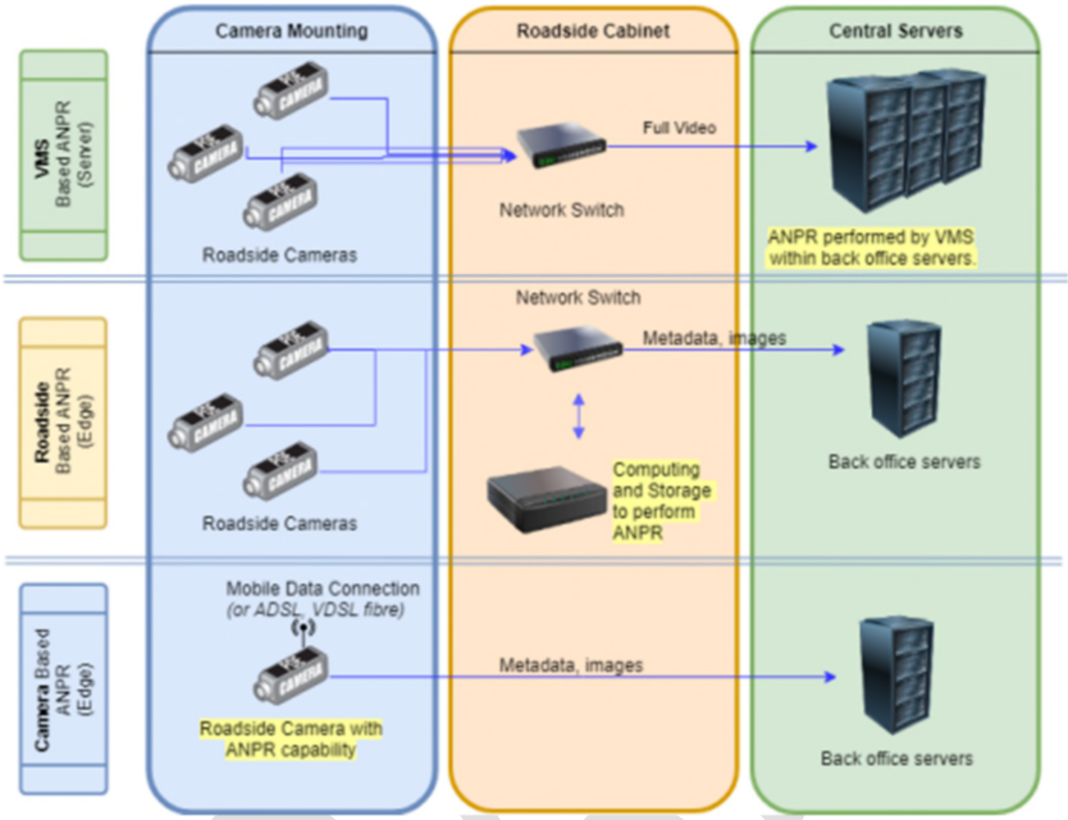
1. Resolution. Higher resolution will make ANPR easier but require more network bandwidth.
2. Frame rate. The higher the recorded Frames per Second the better the image quality and vehicle location of fast moving vehicles but the higher the bandwidth needed.
3. Video compression codec. This determines how the video is packaged and compressed for transmission.
4. Number of cameras

In order to meet ANPR requirements, a minimum of high definition (1920x1080) H.264 (a video compression standard) quality video running at 25fps is necessary. This requires around 5Mb/s per camera. So if 4 cameras were used at a single site then a minimum of 20mbps connectivity would be needed. This necessitates a fibre connection for reliable ANPR installations.

6.8 Edge vs VMS ANPR

With software for ANPR becoming more mainstream and recent technology advances in both GPU and camera image quality, it is now more viable to perform the license plate image processing at the point of detection within the camera hardware. This is commonly referred to as edge processing as it is being done at the edge of the network. Most camera vendors currently offer a level of ANPR edge processing capable cameras or are in the process of adding this capability. These cameras are equipped with in-built computers that can take care of the necessary image processing or at least perform automated tuning within the camera to capture optimal video for ANPR. With edge processing the only output required from the camera is licence plate metadata and a static scene image for enforcement. To avoid streaming full video back to central servers for processing, edge processing can also be performed by off-camera hardware that could be mounted in the roadside cabinet or alternatively in a sealed enclosure. The various ANPR scheme options are shown in Figure 10.

FIGURE 10: ANPR PROCESSING OPTIONS



These various options will be considered in Table 3.

TABLE 3: EDGE PROCESSING CONSIDERATIONS

	Camera Based ANPR (Edge)	Roadside Based ANPR (Edge)	VMS Based ANPR (Server)
Network	Low network requirements. Could operate over a Wifi, DSL, fibre or even a cellular connection. Just power needed.	Same as camera based requirements although video feed from the camera to the cabinet is required.	Very high network requirements from cameras, through network switch and back to VMS servers. This is to support high resolution video streaming.
Camera	Camera must support on-board ANPR so will be higher grade. Fewer options for vendor selection.	Same as server based ANPR	More camera vendor flexibility since limited on-board camera computing required.

	Camera Based ANPR (Edge)	Roadside Based ANPR (Edge)	VMS Based ANPR (Server)
Security	Secure network link between cameras and servers is required. Could avoid physical security issues with cabinet if wireless networks utilised.	Secure network links required between cameras, roadside cabinet computing and servers. May require dedicated roadside enclosure.	Secure network links required between cameras, roadside cabinet and servers.
Server and processing costs	Lowest server costs since all processing distributed to camera network.	Same as edge with the addition of a local roadside ANPR server.	High server costs. Approx. 1 additional CPU core per ANPR camera.
Storage	Low cost on camera storage needed in case of network failure.	Roadside ANPR computer will require low cost storage.	Large server side storage capability may be required if video is stored. ~50GB per day per camera.
Reliability	Less complexity so less chance of failure. Could easily have network and server fall-back options with on-board storage on camera and low bandwidth requirements.	Additional potential reliability issues with roadside technology. UPS would be recommended for graceful shutdown.	Relies on uptime of server and network infrastructure to operate. Limited options for fallback in case of network or server failure.
Accuracy	No option to replay or view video stream so relies on high accuracy of ANPR camera.	Dependent mostly on camera feed quality and ANPR software running roadside.	Dependent mostly on camera feed quality and ANPR software running server side.
Installation	Camera, power and pole required. Optional network connection. Cell reception a minimum.	Camera, power, pole, DSL or fibre, cabinet computer, WAN switch.	Camera, power, pole, fibre, cabinet access, WAN switch.
Maintenance	Low. Just the camera maintenance program of cleaning and tuning. Firmware upgrades and camera settings changes may be required on occasion.	Additional complexity of managing roadside computing hardware. This will require additional monitoring.	Standard camera maintenance program. Additional overhead of network and server performance monitoring to support high bandwidth video streams.

	Camera Based ANPR (Edge)	Roadside Based ANPR (Edge)	VMS Based ANPR (Server)
Upfront costs	Lowest. Just the cameras. No requirement for in-cabinet equipment.	Medium. Cameras, cabinet computing and cellular router or network switch.	Additional server and networking costs.
Ongoing costs	Cellular, wifi or network charges. Low.	Same as camera edge scenario with the addition of roadside computing maintenance.	Lower ongoing camera operating costs but significantly higher server and networking costs.

Edge processing offers the simplest and most reliable solution for ANPR. It is also the only viable option for sites where fibre network connectivity is unavailable. Edge processing supports the option for low cost multi-link networking that can be used to provide system redundancy and resiliency as needed. Even without backup networking, failure modes are better since the cameras can operate autonomously with local storage and computing in the event of network and/or server failure. ANPR accuracy has been found to be on par with server based VMS systems.

Since live video streaming is not required for congestion charging, edge processing would offer the most cost effective and reliable solution with limited downside. Edge processing does not rule out the provision of video feeds into other systems if fibre was available.

Existing cameras could be used for a congestion charging scheme. This would be done by the existing VMS system providing ANPR data into the congestion charging application. This would need to be considered carefully as bringing the VMS system into scheme operation would introduce additional technology reliance. It may make more sense to simply run the systems separately if limited existing cameras could be repurposed.

Advantages of edge processing:

- Reduced network traffic and bandwidth requirements.
- Suitable for sites where no fixed networking infrastructure is available.
- Can operate over cellular connection.
- Accuracy is on par or with server based ANPR.
- Network failure does not result in ANPR failure.
- Distributed computation onto cameras reduces the need for additional server CPUs, server storage and high volume network bandwidth.

Disadvantages:

- Video stream is not recorded and so cannot be replayed if needed.
- Camera cost can be slightly higher to support on-board ANPR.
- Video stream not available for other purposes such as traffic monitoring. This could however be added in as a parallel link if networking was available.

7 Vehicle trip detection

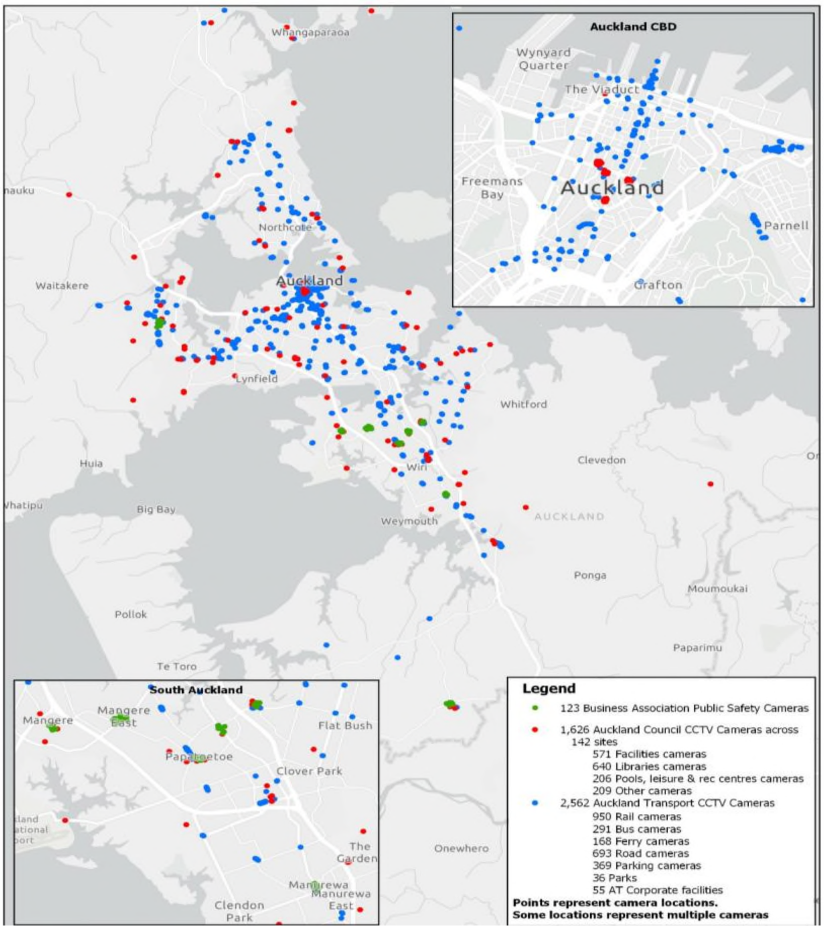
7.1 Introduction

The automated[5] identification of vehicles using ANPR is required for congestion charging. It is required for both the assignment of charges and scheme enforcement. The primary requirement for vehicle detection is that the system is accurate, reliable and not open to manipulation. The vehicle trip detection element is the key part of rolling out any congestion scheme given that it relies on hard infrastructure that cannot be easily changed at a later date unlike the other technology elements of the scheme.

7.2 Auckland camera network

AT currently operates approximately 2,562 CCTV cameras across Auckland. 693 of those are road cameras. Of the road cameras, only 55 are ANPR cameras.

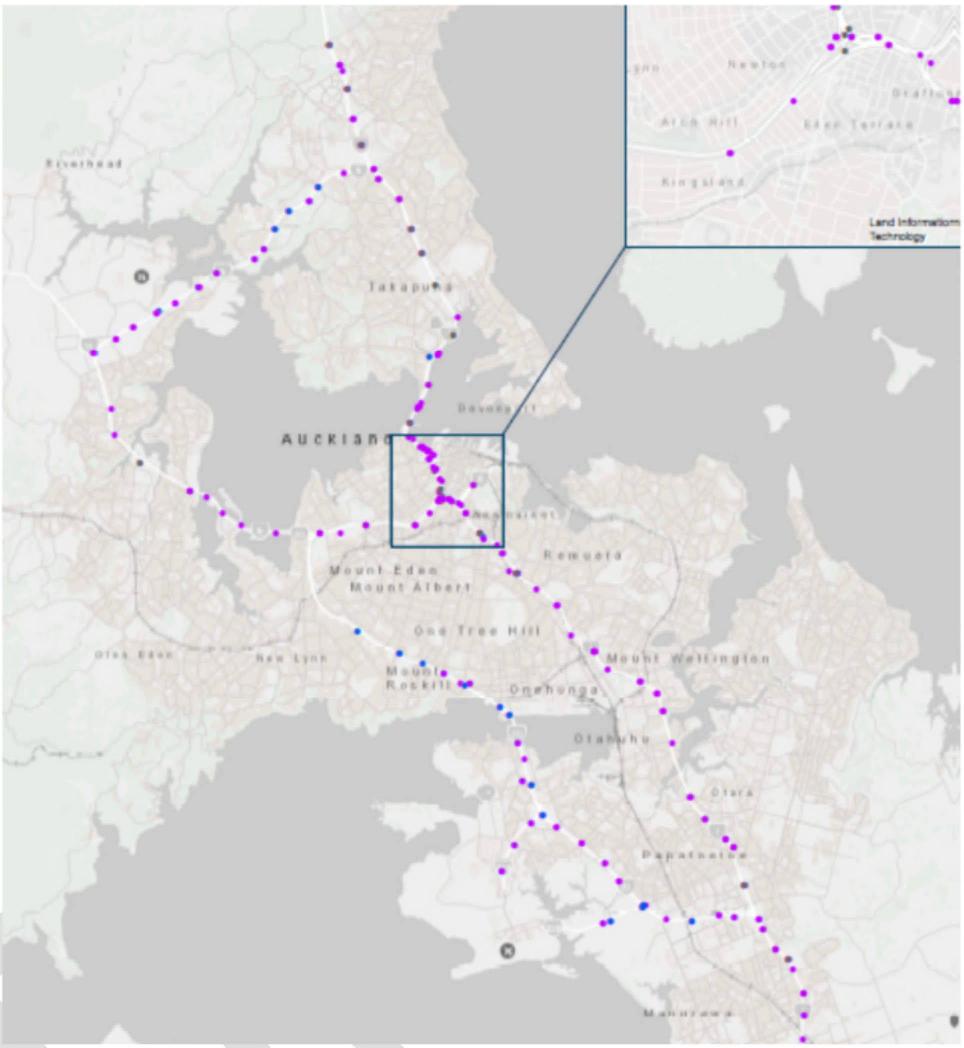
FIGURE 11: AT EXISTING CAMERA NETWORK



[5] Manual decoding of licence plate numbers is not viable for a congestion charging scheme of Auckland's scale. To illustrate if 500,000 charged vehicle trips occurred in Auckland per day, and each image took 30sec to decode, this would require over 4000 human hours of decoding, or 500+ staff working 8 hour days.

NZTA operate over 300 cameras in the greater Auckland area.

FIGURE 12: NZTA CAMERA LOCATIONS



AT has a limited number of cameras being used with a VMS based ANPR solution to enforce special use lane compliance (bus only lanes). It is also used for measuring journey times by recording the time for unique vehicles to travel between fixed locations.

NZTA is using 10 year old Kapsch ANPR technology for existing toll roads. NZTA is also in the process of deploying newer ANPR technology to 13 sites around New Zealand as part of the Weight Right[6] project.

Both NZTA and AT have reported high licence plate read rates using ANPR technology. Existing ANPR systems are reporting accuracy read figures in the 90%+ range with some installations achieving 98%.

[6] https://www.nzta.govt.nz/commercial-driving/trucks-and-tow-trucks/weigh-right-programme/

7.3 Main findings

7.3.1 New cameras

Most of the cameras already deployed across Auckland are not suitable for use in a congestion charging scheme. This is due to ANPR typically not being a design requirement when the cameras were installed. Camera type, illumination, frame rate, resolution, angle and mounting setups would result in 10%-20% ANPR read rates at best.

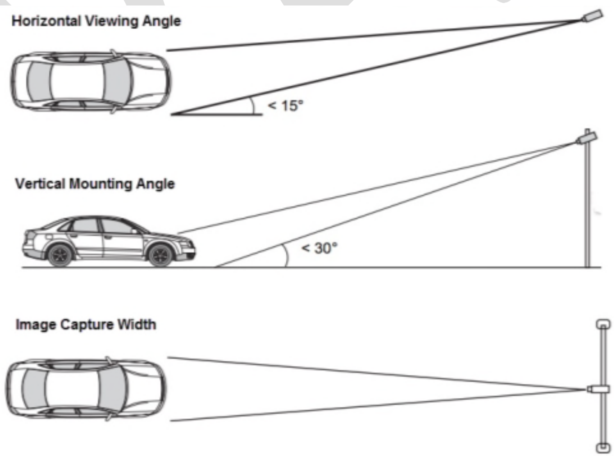
Reusing the existing physical infrastructure at the install sites will however significantly reduce installation and provisioning costs of new camera installations. The cameras themselves make up only a fraction of the overall system costs. If civil works and traffic management plans are required these costs can add up to 20 times the cost of the camera.

Where existing cameras already exist will be the easiest and lowest cost sites to deploy new cameras. Choosing sites where traffic lights are present will be the next easiest as power, networking and poles for mounting are already available.

7.3.2 Camera redundancy

Accuracy levels (of ANPR reads) can be improved through the careful mounting, provisioning and tuning of the camera. Highest accuracy rates occur when the camera is mounted on a gantry, bridge or overpass although it is still possible to achieve a high read accuracy from roadside mounting. More upfront design is required however to consider lighting, angle, sunlight, pole rigidity etc.

FIGURE 13: EXAMPLES OF OPTIMAL ANPR CAMERA MOUNTING RECOMMENDATIONS



Given the relative low cost of additional cameras it is recommended that camera redundancy be used to achieve higher accuracy read rates rather than investing in fewer high end cameras. Table 4 below demonstrates the dramatic read accuracy improvements as additional opportunities for detection are added even using cameras that only have only a 90% read accuracy.

TABLE 4: SYSTEM READ ACCURACY USING 90% ACCURATE CAMERAS

Opportunities for detection	Read Rate
1	90.00%
2	99.00%
3	99.90%
4	99.99%

As the table above shows, even at a low read accuracy of 90%, simply adding one additional camera on the same route will increase the overall chance of an accurate plate read to 99%. It is worth nothing that these are simple mathematical predictions. If the plate could not be read at one site due to obstruction for example, it is possible that it would not be read at an alternative site as well. If the reason was due to poor illumination, angle or sunlight then alternate sites, if well designed to complement other cameras would increase read rates significantly.

Lastly, it is worth considering that so long as drivers expect to be charged when driving in the chargeable zone then behaviour change objectives will likely be achieved regardless of the actual system accuracy. This means that 100% system accuracy would be nice but not critical to achieve the desired congestion benefits.

7.3.3 Backup power

Power to the camera is a risk to operations. This could be mitigated by the use of Uninterruptable Power Supplies (UPS) at each camera site. This additional cost would need to be weighed up against the likely outage frequency. If camera redundancy was available across the charging zone then the need for UPS would be unnecessary and this cost could be saved.

7.3.4 Existing VMS

AT has already purchased a sophisticated VMS package that can be used, among other things, for journey time reporting, automating the detection of bus lane infringements, detecting people walking in out-of-bounds areas such as tunnels and train tracks. The VMS package is also used by ATOC for monitoring traffic.

To use the existing cameras and VMS would require that the existing cameras are well positioned and suited for ANPR. Unfortunately, in most instances, this is not the case. Bus lane and journey time cameras are the exception although even these are tuned for specific lanes and purposes.

The existing VMS system could be extended for use in a congestion charging scheme although this would require significant additional investment in server processing, networking and storage requirements to process the additional cameras needed

For the purposes of congestion charging a VMS system is somewhat over engineered since all that is required for congestion charging is the collection of licence plate numbers and a scene image per vehicle.

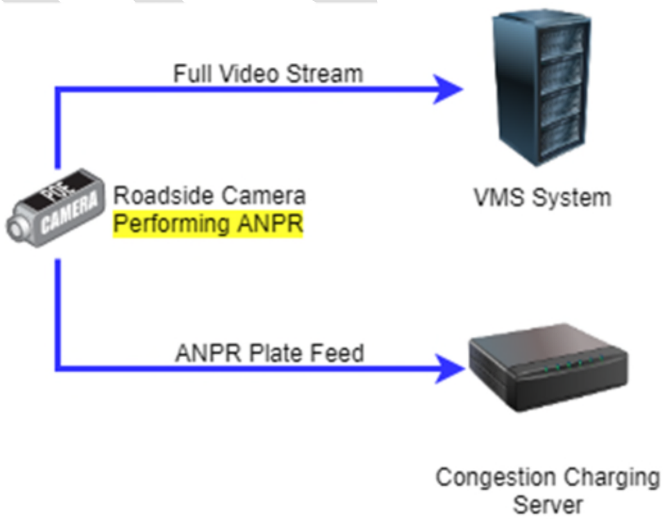
Full video is not required for a congestion charging scheme. The VMS would also become a single point of failure and mission critical for scheme operation.

FIGURE 14: EXISTING CAMERAS - USE VMR TO PERFORM ANPR

To avoid deploying duplicate cameras at existing sites it may make sense to utilise the existing VMS and feed these decoded plates into the congestion charging scheme rather than deploy duplicate cameras in those areas. The cost of linking the VMS system into the operational requirements of the congestion charging scheme, the development of an additional interface and the relatively low costs of new cameras should be considered before this work is undertaken. It is expected that limited camera overlap is more efficient than adding in the complexity of the additional VMS data feed.

For sites where there is overlap with the new congestion charging cameras and future traffic monitoring needs the recommended approach would be to provide a separate video feed from the camera into the VMS to support other system requirements. This avoids the need for reliance on the VMS system for congestion charging and avoids duplicate future cameras. To support the video feed to the VMS, a fibre connection would be required unless video quality was reduced. Since ANPR would be done at the camera a lower quality video feed into the VMS would be feasible.

FIGURE 15: NEW CAMERAS - CAMERA PERFORMS ANPR AND VMS ALSO RECEIVES VIDEO FEED



7.3.5 Cameras

A new distributed edge based ANPR camera network must be deployed across the proposed charging areas. Optionally, if a significant number of existing ANPR cameras overlap with the congestion charging scheme locations then a connector between the VMS system and the congestion charging rules engine could be built. This would need to be evaluated once all the sites for congestion charging are identified.

In addition, there is potential to reuse sites that already have cameras installed. This will reduce installation and provisioning costs. Networking will also already be available at these sites.

Leveraging knowledge within the AT ProVision team for new camera installation will ensure optimal mounting setup and configuration of cameras. Existing relationships with networking consultants and independent camera consulting firms should be used to design an optimal system.

7.3.6 Privacy

Due to the private nature of personally identifiable ANPR data collected from the congestion charging scheme it is imperative that security be designed into the solution from the beginning. This requires necessary compliance with the NZ Information Security Manual[7].

End-to-end network security should be designed into the system from the outset. This includes secure access to the cameras all the way to the operational systems and web applications. Physical network security cannot be relied upon due to the easy access to roadside cabinets. This means that cameras must support secure protocols such as HTTPS or VPN.

[7] https://www.gcsb.govt.nz/publications/the-nz-information-security-manual/

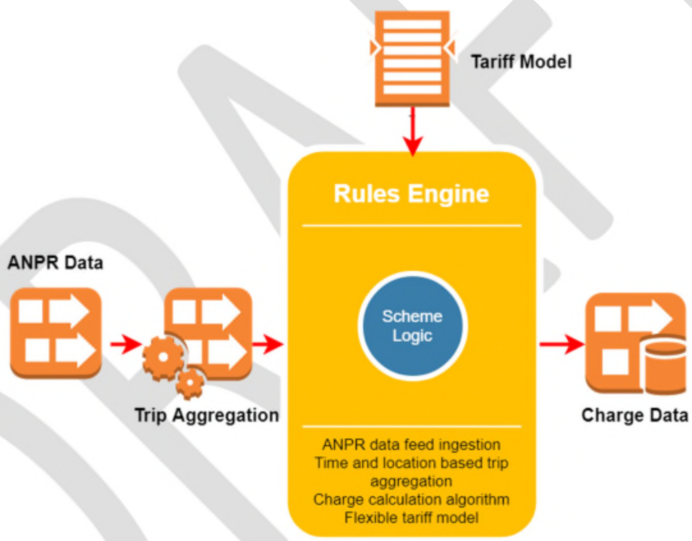
8 Rules engine

8.1 Introduction

The Rules Engine is the application that operationalises the tariff policy. The Rules Engine is where the ANPR data stream and metadata from all the cameras is processed and aggregated. The rules engine algorithm can calculate charges based on the location, time and duration of individual vehicle journeys and will output the charge data assigned to unique vehicles into the back office systems.

The Rules Engine is required to support high volumes of ANPR data as well as be highly scalable to support increases in future traffic volumes and possible scheme expansion. It is envisaged that more than a million chargeable events could be generated per day. At peak times the system should be able to support the generation of up to 200 chargeable events per second which could be sourced from 1000 vehicle detections per second depending on camera redundancy and distribution. It must also be designed to be flexible enough to facilitate changes to the tariff model.

FIGURE 16: RULES ENGINE OVERVIEW



8.2 Auckland toll road system

The proprietary NZTA toll road system utilises many similar technology elements to an ANPR congestion system and is the only system with a suitable rules engine for comparison. Unfortunately, the NZTA system was never designed to support the kind of scale that an Auckland congestion charging scheme would require. Volume across the three NZTA toll roads is around 40,000 trips per day. The number of trips expected for the full Strategic Corridors scheme could be over 1 million per day. Location, time of day charging and vehicle trip aggregation are fundamental elements to a congestion scheme. These are currently not supported within the toll roads system which implements a simple mapping of single trip detection to fixed single vehicle charge.

8.3 Main findings

Given that Auckland is looking to design a modern congestion charging scheme and there is nothing already available to meet the current and future design objectives, it is necessary that a new rules engine be built. This is an opportunity to use a modern technology stack that facilitates a highly scalable and efficient processing of the ANPR data. In addition, it is an opportunity to shift to a cloud based hosting model that brings with it many operational and computing efficiencies. An example of a cloud based data processing option would be to use Amazon Web Services (AWS) Kinesis Data Streams or Apache Kafka on AWS.

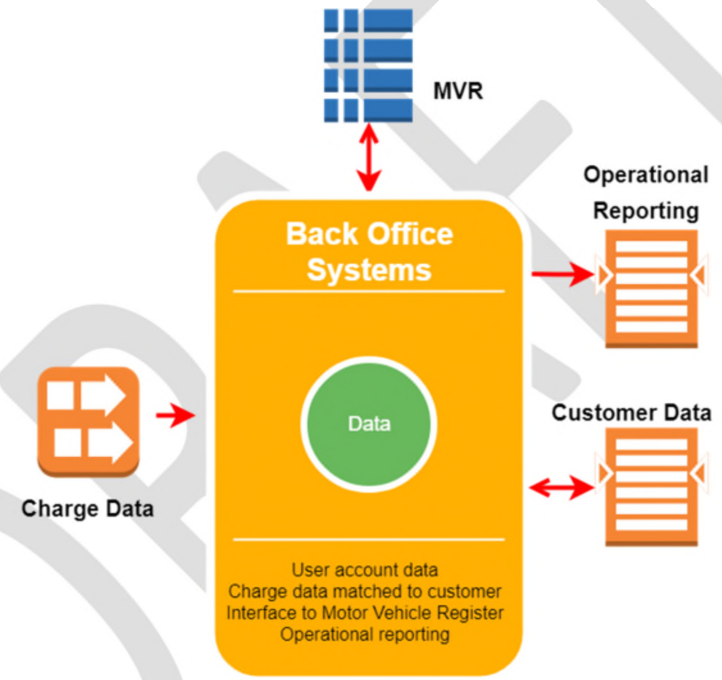
Whilst the NZTA Kapsch toll road system is still fit for purpose it is almost out of contract. This review suggests that there is an opportunity that the Auckland Congestion Charging technology would be well suited to replace the toll road system when the maintenance and warranty period end. This has the advantage of a single entity managing all ANPR charging technology systems within NZ which brings significant operational and cost efficiencies. In addition it will be possible to test and harden the congestion charging system side-by-side with the existing Kapsch toll road system. This provides the opportunity to evaluate the comparative accuracy of each system within a controlled environment. This is considered best practice system development.

9 Back office systems

9.1 Introduction

The Back Office System receives vehicle charge data output from the Rules Engine. This data is then matched to customer accounts where the account balance is updated. Customer data is stored within the back office and may be updated via the User Account Management functions. The Back Office connects to the Motor Vehicle Register (MVR) via the Common Data Interface (CDI) so that registered vehicle owners can be automatically updated within user accounts and registered owners can be contacted when vehicles are not found to be within the existing accounts database. Operational reporting is also sent from the Back Office to operations teams such as Customer Service, Technical Support, Scheme Monitoring, Collections and Enforcement.

FIGURE 17: BACK OFFICE OVERVIEW



Exiting back office systems within AT and NZTA were reviewed for applicability for repurposing within the congestion charging back office systems. Back office systems included those for public transport ticketing, parking, bus lane infringements and toll road systems. It was hoped that it would be possible to reuse some of the functions within these back office systems such as interface with the MVR and user account charge data management. The existing back office systems will be discussed in the following sections.

9.1.1 Thales back office system

AT procured the Thales (French company) integrated fares system for public transport ticketing. It is commonly referred to as HOP which is the smart card used to pay for fares on public transport. Transactions may be viewed and cards topped up via the myAT system that integrates with the Thales back office systems. The pre-pay HOP card system was designed specifically around unique card balances and the debiting of these when public transport journeys are taken. For example, a single account can contain multiple HOP cards each with their own balance. Trips are charged at the time of travel with the HOP card transaction occurring between the card and the reader with no immediate interaction with the back office required. The back office system for operating the HOP cards is very different to the requirements for a congestion charging scheme where the charge data arriving is vehicle based.

9.1.2 Kapsch back office system

The bespoke NZTA toll road system developed by Kapsch (Austrian company) utilises many similar technology elements to an ANPR congestion charging system. The existing system however was never designed to support the kind of scale that a congestion charging scheme would require. Volume across the three NZTA toll roads is around 40,000 trips per day. The number of chargeable trips expected for the Auckland Congestion Charging scheme could be over 1 million per day. Time of day charging and vehicle trip aggregation are fundamental elements of a successful congestion scheme. Neither of these is currently supported within the Kapsch system.

For the Kapsch system to achieve 97% accuracy of plate reads, approximately 9% of all images are reviewed manually by service staff. 9% of a potential 1 million chargeable trips within the Auckland Congestion Charging scheme would result in 90,000 manual reviews per day. This would be simply unworkable.

9.1.3 AT parking back office systems

Auckland Transport uses the "Pinforce City Wide" product from DCA (Australian company) for their integrated parking solution. ANPR is not currently used for parking enforcement but may be considered in the future. The back office systems within Pinforce are specifically developed for streamlining the manual issuing of parking infringements.

When issuing parking tickets, registered vehicle owner lookup is performed manually using the MotoChk service. The infringement is then manually loaded into the Auckland Council Infor Pathway system for collection.

9.1.4 AT special lane enforcement back office systems

Auckland Transport utilise a VMS system for the detection of bus lane infringements and ANPR for vehicle detection. Bus lane infringements are reasonably low volume and so detections are manually reviewed by staff prior to the infringement being manually loaded. It is also a legal requirement for each infringement to be manually reviewed.

As with the issuing of parking tickets, registered vehicle owner lookup is performed manually using the MotoChk service and the ticket manually loaded into the Auckland Council Infor Pathway system for collection.

9.2 Main findings

A new, purpose built back office system is required for the successful implementation of an Auckland Congestion Charging scheme. No existing system can be easily or cost effectively repurposed for use in a high volume, dynamic and modern congestion charging scheme. Existing proprietary, closed systems are not suitable for modification or modification would come at considerable cost.

There is an opportunity that the Auckland Congestion Charging back office would be well suited to replace the toll road back office systems when the maintenance and warranty period end. This has the advantage of a single entity managing all ANPR charging technology systems within NZ which brings significant operational and cost efficiencies.

Of the current $2.40 toll on the Northern Gateway, $0.70 goes towards operational costs. It is expected that when building a new back office system with modern best practise technologies the operational overhead would be significantly lower.

Whilst the Kapsch toll road system is still fit for purpose, it is 10 years old and almost out of contract. Modifying the existing Kapsch back office systems to support congestion charging would be a considerable and costly undertaking.

Other AT back office systems such as those used for public transport ticketing, lane enforcement and parking are not well suited for use in a congestion charging context. The base requirements are simply too divergent and repurposing the technology would be difficult, costly and would most likely result in a sub optimal outcome.

By developing a new back office system, applications and data storage, the opportunity exists to use modern, cost effective technologies that are fit for purpose in delivering an optimal and successful congestion charging scheme.

Exports from the Back Office system could provide:

- Time of day traffic flow, speed and volume reporting.
- Vehicles of interest query (Police).
- Video feeds into ATOC VMS for incident and traffic monitoring.

A core component of the back office system is the output of operational reporting. These reports will support the measurement of scheme success using metrics such as time of day traffic flow, speed and volume reporting. Heat map or similar visual analytics could be generated from the vast amount of data being collected that could assist with reviewing scheme elements such as charges, time bands and coverage. Future expansions or scheme changes will need to be informed by some of the data being collected from the system and so this data should be readily available and easily presented.

If desirable, it is also possible to leverage the created telemetry network to support the addition of other roadside systems of sensors, such as air quality or traffic noise. It is noted that these systems are not linked or dependent on the congestion charging scheme (ie they could be installed today in many locations where the telemetry network already exists). However, data from these additional systems (eg air quality data) could be added to operational reporting metrics for information.

10 User account management

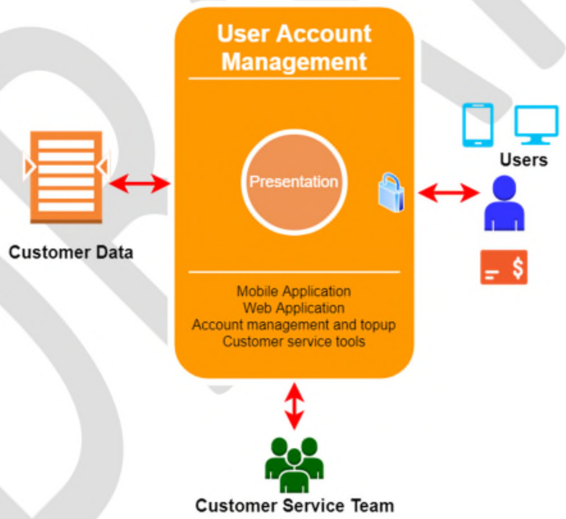
10.1 Introduction

User account management encompasses the presentation of user data and is the place where customers can easily interact with their charge account via their smartphone or computer. This will include a web front end as well as a mobile app or mobile web application. User account functions that are likely to be carried out via the application include:

- View current balance
- View trips and payment history
- Update profile details and login credentials
- Add/remove vehicles
- Top-up account and setup automatic payments
- Apply for a discount or exemption
- Contact customer service

The Customer Service team will also be able to interact with the User Account system to assist with customer enquiries.

FIGURE 18: USER ACCOUNT OVERVIEW



10.2 Auckland account management systems

10.2.1 myAT

The myAT web application, whilst functional, is currently very HOP card centric and not designed for an optimal mobile experience. It would, however, be possible to integrate the Congestion Charging web app into the myAT domain, similar to what was done with AT Park. As can be seen with AT Park, this approach would however run the risk of usability concessions particularly around consistency of user experience.

10.2.2 Toll road web application

Some of the functions and learnings of the NZTA web application could be reused. It was identified however that limitations with the current NZTA back office systems limit the suitability of the system for expansion. For example, if a user account has hundreds of vehicles registered (such as a rental car company), system usability is severely impacted. Overall, the building of a new account management tool from the ground up with modern technologies is seen as an opportunity to modernize the functionality and improve usability. This is not considered to be an onerous undertaking given the overall project size and scope.

10.3 Main findings

10.3.1 Web application

A new web application should be built to support user account management. The app should be secure, friendly, fast, simple and easy to use. The progressive web app should be built using modern cross platform technology such as Angular, Vue or React so that it could easily be deployed as a native mobile app (iOS or Android) in the future if needed.

The web app will interface with the back office systems to provide a visual way to: View Trips; Add/Delete Vehicles; View Account Balance; Payment Top-up and Contact Support. The back office systems should interface with the MVR via the CDI so that it can be notified when registered vehicle owners change and to confirm valid licence plate numbers. Users will need to be notified of these changes.

10.3.2 Single login

It is preferable that transport users would have a single account to manage all their transport needs in Auckland. For example, a single login should provide access to your public transport account (myAT), toll roads (NZTA toll roads), and congestion account. With this in mind it would make sense to utilise existing user databases for any congestion charging scheme to avoid customers having to make new accounts.

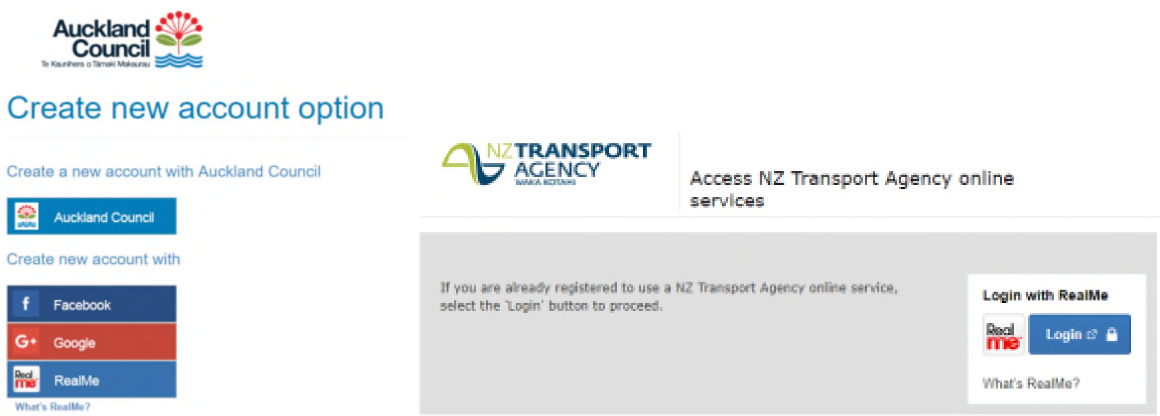
Best practise for account login is to use email address as username and a unique customer selected password. This avoids customers forgetting their username and also provides a method for recovering forgotten passwords. myAT already has this configuration whilst NZTA[8] uses account number as username and a pin rather than password.

An alternative would be to add support for RealMe which is a single login service created by the government to support single sign in for government agencies. RealMe was designed to enable customers to access a range of Government and private services with a single username and password. NZTA already offer RealMe login for driver licencing. Auckland Council also support RealMe. 39

[8] NZTA has 267,000 active accounts used for tolling on the toll roads. Of the vehicles that travel on all toll roads, 89% are on account.

organisations currently use RealMe as their login. RealMe is mandated for all Government IT projects[9]. The 2019 Wellbeing Budget has allocated $66.1 million to *Supporting the Operation of RealMe*[10].

FIGURE 19: AUCKLAND COUNCIL AND NZTA LOGINS SUPPORT REALME



10.3.3 Single payment

Similar to the desire for a single login for transport operations within Auckland, it is also recommended that there is a single payment system to avoid duplication. For example, it is a poor user experience for Auckland road (toll road, congestion, and parking) and public transport users (AT HOP) to have to update their credit card details in 4 systems when they change.

Even within AT, AT Park is a separate system that uses different payment details from myAT HOP. Access into ATPark can be made via myAT, but the systems are very separate.

If the congestion charging system picked up the management of the toll road system, payments could at least be integrated easily.

10.3.4 Customer services

Although not a technology element, the customer services teams within AT and NZTA could be expanded to support the congestion charging scheme. The Account Management application must provide access for customer services teams to easily support users with enquiries such as trip query; password reset; forgotten username; payment issues; vehicles on wrong account etc... These functions, amongst others, should be designed into the User Account Management application.

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[9] https://www.digital.govt.nz/products-and-services/buying-products-and-services/

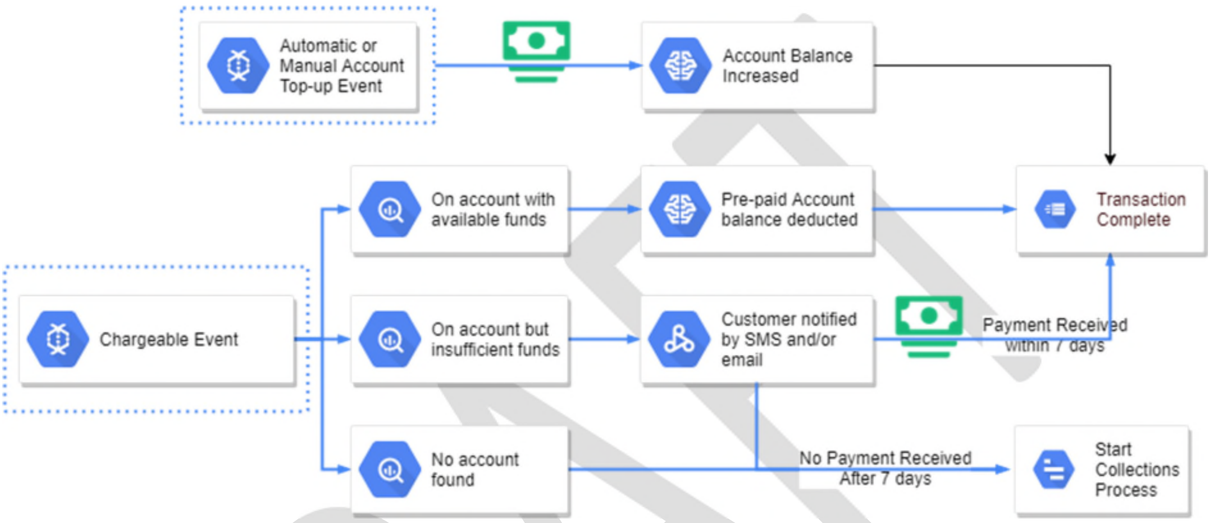
[10] https://treasury.govt.nz/sites/default/files/2019-06/b19-wellbeing-budget.pdf page 82.

11 Compliance and enforcement

11.1 Introduction

Compliance and enforcement involve the matching of chargeable events against payments received and the collection of payments for unpaid vehicle trips within the charging zone. Figure 20 illustrates a possible process flow to initiate the collections process if payment for the charge is not received.

FIGURE 20: ENFORCEMENT TRANSACTION FLOW



11.2 Auckland compliance and enforcement systems

AT operates a parking and special vehicle lane enforcement system. This system is used to issue tickets and collect payments for violations. The Motochk website is used to manually confirm vehicle registration details prior to ticket details being issued. These are then batched up and verified again overnight against the MVR to confirm data entry accuracy. This allows for anomalies to be flagged the next day prior to the tickets being issued. This is used instead of an automated real time link directly into the MVR.

To assist with customer service and management functions, AT use the Infor Pathway software package. This package includes capabilities to help local authorities manage billing and debt collections effectively. The enforcement teams within AT use this system to issue infringement notices and ensure payment is collected.

NZTA toll roads also have capabilities to follow up on vehicle owners that have not paid their tolls. If payment is not received within 7 days then a reminder notice is sent with an additional administration fee. If after 30 days the toll is not paid, a $40 infringement fee is added to the toll. After this, debt collection action may be taken to recover outstanding fees.

Table 5: NZTA toll road fees

Fee type	Description	Amount
Administration fee	To cover the cost of issuing and processing a payment for a Toll Payment Notice	$4.90
Service fee	To cover the costs of processing a payment for toll purchases through the contact centre	$3.70
Transaction fee	To cover the costs of purchasing tolls through the cash payment option	$1.20
Infringement fee	Additional fee charged when an Infringement Notice is issued for non-payment of a toll payment notice	$40.00
Dishonour fee	To recover costs due to insufficient funds or credit available through your nominated payment method	$20.60

11.3 Main findings

Part of the back office operational process is the output of non-account vehicles that will require follow-up for payment and potentially debt collection. Existing enforcement systems operate within AT for parking and special lane infringements and within NZTA for toll road collections. These systems should be reused and expanded if necessary for the Auckland congestion pricing scheme.