WORKING PAPER

The Congestion Question

Could road pricing improve Auckland's traffic?

Workstream 2

GNSS Technology Summary

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Working Draft vA

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1 Purpose

The question of whether Global Navigation Satellite System (GNSS) technologies could be used for implementing congestion pricing (either via an on-board unit (OBU) that is installed in a vehicle or via a smartphone app) is often raised by stakeholders and members of the public.

This briefing note addresses these questions in the context of The Congestion Question (TCQ).

2 Executive Summary

To implement an automated congestion charging scheme it is necessary to identify the location of vehicles within the charging area (or at a charging location). Automatic Number Plate Recognition (ANPR) using roadside cameras is widely accepted as the standard technology for this purpose and is the only viable option for scheme enforcement. GNSS technology is worth consideration as an option to augment ANPR for vehicle trip detection.

GNSS works by using in-vehicle devices to receive satellite signals and convert these into vehicle position and trip data that is then transmitted to a back office system for processing and billing. Whilst ANPR technology is still required for scheme enforcement, adding GNSS offers the primary advantage of being able to identify vehicle journeys even where ANPR infrastructure is not present. GNSS is not tied to roadside infrastructure and so can apply pricing that includes consumption of road use by distance (and/or time). This offers unrivalled flexibility in charging scheme design and options.

Internationally, no ubiquitous all-vehicle charging scheme exists that utilises GNSS location technology. There would be significant technical risk in being the first to develop and roll out such a scheme. Whilst technically feasible and thoroughly evaluated in many countries, all designs were discarded for simpler and more cost effective solutions.

In NZ, electronic road user charging (eRUC) OBUs contain GNSS technology. However eRUC does not necessitate any location information, only distance information. eRUC OBUs measure distance via a connection to the vehicle odometer or speed sensor and not through using GNSS. Commonly used GNSS tracking devices for commercial fleet tracking services have not been designed for a road charging application and so the security and accuracy would not meet the evidential requirements for a congestion charging scheme. To meet these requirements, a ground up approach would be required with considerable development and device cost.

Privacy concerns have also been identified with proposals for GNSS based road charging systems because of the need to collect vast amounts of vehicle location data including information for travel which is not subject to charging. Privacy issues tend to get raised by opponents along with other issues as a reason to fear road pricing, primarily out of concern that the government or companies will record all vehicle movements and potentially misuse this data. Privacy concerns ultimately led to the abandonment of many such schemes internationally. In contrast, the public perceives ANPR as less intrusive than GNSS as they are already comfortable with its usage for existing toll roads.

Adding GNSS capability to any congestion charging scheme brings with it significant additional costs and risks which would need to be weighed up. Some of these include:

- No suitable light vehicle OBU is available off-the-shelf. One will need to be developed from the ground up which poses significant research and development (R&D) cost as well as technical, performance and timing risks.
- More than a million OBUs will need to be installed into vehicles, necessitating a major and costly one-off exercise.
- OBU cost is estimated at $NZ180-$NZ250 each. There would also be a NZ$10/month (approximate) ongoing charge for cellular and other charges even if the vehicle is not used. With approximately 1.2 million vehicles registered in Auckland, this would equate to an upfront cost of $216-$300 million for the OBUs and an ongoing cost of $12 million/month (or $144 million/annum) for cellular and other charges.
- Additional back-end server applications, processing and storage will be required to receive the OBU data and correlate this with ANPR data feeds.
- Even infrequent road users will require an OBU or be penalised with an infringement or day pass cost. This runs the risk of penalising infrequent road users with an extra cost which is counter to TCQ's objectives. Based on observations of the Stockholm scheme, there are reasonable numbers of out of town visitors, in the order of 1,000 per day.
- Providing the high quality and reliable installation of OBU into all road users vehicles would be a considerable challenge. Low quality installs could result in OBU failure, vehicle warranty and reliability issues, and low user satisfaction.
- Device failure could result from users purposefully or accidentally disabling the OBU. GNSS signals can be blocked or faked. Device enforcement would be very difficult and seen as overly intrusive.
- Rolling out mapping, tariff and software updates to all the devices poses significant timing and transmission challenges when engineering and scheme upgrades take place. Data transmission costs may become quite high during these times as well.

Whilst smartphones contain GNSS capability and avoid the need for an in vehicle OBU, several attempts to use smartphones for road pricing in the USA found serious shortcomings in the usage of smartphones for congestion charging. The main issue being that a smartphone tracks an individual not a vehicle. This means other trips like public transport and bicycle trips run the risk of being charged. In addition not all road users will have a smartphone or have one that would be compatible with such an app. Smartphones are however desirable as a channel for user account management. Any scheme would benefit from the development of an easy to use and well-designed account management smartphone and/or web application. This app could be extended in the future for voluntary opt-in location based charging pilots. These pilots could be used to gauge public acceptance and address usability, privacy and technical risks around potential future GNSS road charging.

In conclusion, the significantly higher upfront and ongoing costs; user complexity, technical risk and privacy concerns of introducing a GNSS scheme on balance outweigh the potential benefits at this time. Since ANPR cameras are generally required for the enforcement of any congestion scheme it is logical and favourable, cost wise, to begin by utilising these same cameras and back-end systems for vehicle trip detection and charging as well. A scheme primarily utilising cameras 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.

3 GNSS

3.1 What is GNSS in a road pricing context?

Congestion pricing systems require the identification of a vehicle's location at specific times. The technology most commonly used to identify a vehicle at a point location is automatic number plate recognition (ANPR) via a camera. GNSS technology is an additional technology that is often discussed in the context of road pricing. GNSS systems determine a vehicle's location based on an in-vehicle device receiving satellite signals. Satellite signals can be received in a vehicle via an on board unit (OBU) or potentially, via a smartphone. These devices then record trip information and transmit it back to a central server for processing and billing. This enables complete journey identification and charging.

3.2 Why use GNSS?

Using GNSS it is possible to track a vehicle wherever it travels. This offers the advantage of being able to implement a scheme that encompasses the complete roading network. GNSS technology enables the development of a congestion pricing scheme based on time, location and distance. This provides ultimate flexibility in charging scheme design as charging areas can in theory be added or removed dynamically.

GNSS has the key advantage of not being tied to roadside infrastructure and so can apply pricing that includes consumption of road use by distance (and/or time). This provides unrivalled flexibility in charging scheme design and options.

3.3 Where are GNSS charging schemes used today?

- Globally, no ubiquitous vehicle charging scheme exists that utilises GNSS technology.
- Whilst technically feasible and thoroughly evaluated in many countries, all designs have been discarded for simpler and more cost effective solutions.
- Singapore is planning to add GNSS capability into the OBUs used within their urban congestion pricing programme in 2020. However, gantries with ANPR and tag readers will still be utilised for vehicle detection, enforcement and charge calculation.
- GNSS technology is used as part of heavy vehicle road charging systems in six European countries. These schemes are for charging heavy vehicles only and mainly on motorways. No scheme uses GNSS OBUs for charging light vehicles yet. Belgium is one of the more recent schemes and allows for the self-install of the small lunchbox size OBU via the cigarette lighter plug. With some reengineering it is conceivable that these types of OBUs could be used for light vehicles.
- In NZ, vehicles over 3.5t are subject to a distance based Road User Charge. These road users may elect to install an OBU instead of running a mechanical hubodometer to record vehicle distance. These eRUC OBU contain GNSS technology however it is not the primary method used to

measure distance. Distance is measured via a connection to the vehicle odometer or speed sensor. GNSS is used to support value-added services for eRUC customers such as fleet management.
- GNSS tracking services are commonly used for commercial fleet tracking. These devices have become relatively common although they have not been designed for a road charging application and so the security and accuracy would not meet the evidential grade required for a congestion charging scheme. To meet these requirements, a ground up approach would be required with considerable development and OBU cost.

No ubiquitous, all vehicle, complete road network GNSS based scheme exists globally. There would be significant technical risk in being the first to develop and roll out such a scheme.

3.4 Privacy concerns with GNSS

Early implementations of congestion pricing identified some sensitivity to privacy as an issue, with both Singapore and London conscious of the need to protect individual privacy. Privacy is much more likely to be a concern for proposals for GNSS based systems than others because of the need to collect vast amounts of vehicle location data including information for travel which is not subject to charging. Privacy issues tend to get raised by opponents along with other issues as a reason to fear road pricing, primarily out of concern that the government or companies will record all vehicle movements and potentially misuse this data. Privacy concerns ultimately led to the abandonment of many such schemes internationally.

Although privacy protections can potentially be designed into a GNSS based system, misperceptions and lack of proof about how the technology works can mean that a narrative about “spy in the sky” or “tracking the public” can quickly gain credence, raising concerns that the scheme is a Trojan horse for mass scale government surveillance. GNSS is often related with invasive government “tracking” and the data could be applied for other traffic enforcement purposes or wider law enforcement purposes. In addition, there are likely to be concerns that such data could be sold for commercial use. By contrast, the public perceives ANPR as less intrusive than GNSS.

Building privacy into the technology is possible but technically difficult due to the opportunity for malicious parties to affect the distributed system in so many ways. Even more difficult is the task of proving that the system is technically secure and data stored is private.

4 On Board Units (OBUs)

GNSS road pricing systems require each vehicle to report location/distance based charging information. This can be implemented via OBUs that determine a vehicle's location based on receiving satellite signals. The OBUs record time and position data, which is then processed into trip data and transmitted via wireless communications to a central server for matching to a set pricing scheme for bill generation. A smartphone could also potentially be used and this is discussed in Section 5.

To support pricing with variation by road, GNSS must be used with map-matching in the vehicle OBU or back office to charge by location and time of day. To facilitate this, Geographical Information Systems and digital maps must be kept up to date with current chargeable routes and rates.

GNSS OBUs are fixed to a single vehicle and require limited to no user interaction once an account is setup. A simple light could indicate whether the device is functional.

4.1 OBU Considerations

Unlike ANPR camera based schemes, GNSS based systems require a location transmitting device in every vehicle. This introduces many additional considerations:

- Development of a GNSS solution will take considerably more time and expense than an ANPR solution, because:
    - No light vehicle suitable OBU is available off-the-shelf and so this will need to be developed from the ground up which poses significant technical, performance and timing risk.
    - More than a million OBUs will need to be installed into vehicles registered in Auckland, necessitating a major and costly one-off exercise.
    - OBU cost is estimated at $NZ180-$NZ250 each ($216-$300 million if all of the 1.2 million vehicles registered in Auckland have an OBU installed).
    - OBUs would incur an additional operational cost of around $10 per unit per month for cellular and other ongoing charges ($12 million/month (or $144 million/annum) for all of the 1.2 million vehicles registered in Auckland).
    - Additional back-end server processing will be required to receive the OBU data and correlate this with ANPR data feeds.
    - An ANPR network is required in any case for enforcement.

- GNSS OBUs for road charging have yet to be proven in full operation for network road pricing, raising considerable engineering and political risks.
- Even infrequent users will require an OBU. This runs the risk of penalising infrequent road users with an extra cost which is counter to the scheme objectives.
- Unlike a smartphone or removable device, a permanently mounted OBU will be a reminder of continuous vehicle tracking. This will raise additional privacy concerns with vehicle users, particularly when non-chargeable vehicle trips are undertaken.

- Providing the high quality and reliable installation of OBU into all road users vehicles would be a considerable challenge. Low quality installs could result in OBU failure, vehicle warranty and reliability issues, and low user satisfaction.
- Temporary installs using the cigarette lighter plug is possible. It does however mean that cables will be hanging over the dashboard. The plug would also be unusable for other purposes like phone chargers. Plug reliability would need to be considered.
- Device failure could result from users purposefully or accidentally disabling the OBU. GNSS signals can be blocked or faked. Enforcement could be very difficult and seen as overly intrusive.
- Cellular coverage to communicate charge data will need to be considered.
- GNSS black spot coverage will need to be considered as signals can be blocked in or by tunnels, tall buildings, car parking buildings, trees etc.
- Rolling out mapping, tariff and software updates to all of the devices poses significant timing and transmission challenges when engineering and scheme upgrades take place. Data transmission costs may become quite high during these times.
- Since there is now a device in the user's vehicle there is increased opportunity for manipulation. Security of data recording and transmission would need to be carefully designed. OBU theft and data hijacking could take place. Network and vehicle penetration using OBU data connection could compromise scheme performance and vehicle safety. OBU security is technically difficult and expensive to achieve.
- Having a "black box" mounted on the dashboard of every vehicle will raise visual concerns with many vehicle owners.
- A system to process change of OBU ownership will be required.
- A GNSS based charging system raises considerable issues and risks around legal challenges and evidentiary standards untested in any jurisdiction.

5 Smartphones

5.1 What role can smartphones play in congestion pricing?

As smartphones have gained a large market share worldwide, the idea of using smartphones that contain GNSS technology for urban road pricing has been raised. Compared to an OBU based GNSS scheme, smartphones save on hardware and installation related costs and potentially provide a more intuitive and familiar user experience.

Smartphones do have a place in a well-designed modern congestion pricing scheme. Smartphones however cannot be used in isolation because:

- Not all road users have a smartphone.
- Supporting all makes, models and age of smartphone would be very problematic and expensive
- An ANPR camera network is still required for enforcement

Smartphones can provide a user-friendly channel for payment and account management. With the support of an ANPR camera network, a smartphone based solution is technically feasible once mass smartphone adoption is reached. It is suggested that once a successful ANPR based scheme has been implemented that a GNSS based smartphone scheme be considered on a voluntary opt-in basis for experimentation with complementary distance based or wider charging models.

5.2 Smartphone considerations

- Smartphones are typically carried by a person and therefore not linked to a vehicle. The smartphone application must provide a simple and reliable method to link the smartphone to a specific vehicle, likely via the number plate. If this is not done correctly at the right time then charging issues will occur.
- A GNSS smartphone app will be tracking the individual not the vehicle. This may accidentally (or intentionally) include the tracking of an individual outside the necessary chargeable vehicle trips or even when the person is removed from their vehicle. Privacy concerns around government tracking and citizen surveillance will be greatly heightened.
- Since the smartphone is tracking the person and not the vehicle, complexities around multiple smartphones in a single vehicle will need to be resolved.
- The app will need to reliably and accurately not charge for trips taken on public transport, taxis, bicycles and by foot. This cannot be reliably done automatically and so will rely on the user nominating the mode of travel. It is therefore likely to result in incorrect or erroneous trips being reported.
- The system will rely on the user to update the vehicle identification information (eg number plate) each time the smartphone is used in a different vehicle.
- The development and testing of a smartphone application that is compatible on a variety of platforms will come at a significant cost.
- There would be further costs to develop the technical integration between the smartphone application system and the back office/billing systems of the scheme.

- Smart phones are susceptible to hacking and manipulation, raising significant security and performance issues around their use for road charging.
- If an OBU system was selected as the desired congestion charging approach then an optional smartphone application could be developed to reduce OBU costs for those users who have compatible smartphones. This would however increase scheme costs significantly as there would need to be a smartphone application developed as well as OBU.
- Usability issues requiring a significantly higher customer support effort will dramatically increase cost and reduce user satisfaction. Common usability issues include: the user forgetting to run the app; phone not on; lost phone; broken phone; forgotten phone; phone assigned to wrong vehicle; phone compatibility issue; incorrect charge for public transport or non-vehicle based travel; app not running; phone battery not charged; app conflict and interference; location services not selected; etc…
- A smart-phone based charging system raises considerable issues and risks around legal challenges and evidentiary standards untested in any jurisdiction.

5.3 Where are smartphone applications used for road charging today?

- Several attempts to use smartphones for road pricing have occurred to date in the USA. However, trials in the US states of Minnesota, Oregon, California and Washington, indicate serious shortcomings in usage of smartphones as the primary technology for road pricing. The tests, however, also suggest smartphones are excellent personal interface devices for account management, payment and reporting, when matched with primary vehicle identification technologies such as ANPR.
- Smartphone applications for tolling exist in the United States and have been developed in Australia, but in all cases they rely on vehicles being declared crossing charging points on major highways (where there is little risk of diverting from the charging point).

6 Frequently asked questions

Could you deploy less ANPR cameras for enforcement if you implemented a GNSS based scheme and therefore lower the ANPR system costs?

Yes you could install less ANPR cameras but this would not reduce the ANPR system costs that much. This is because the individual cameras make up a small portion of the overall system costs. The back-end ANPR system and applications are required regardless of the number of cameras and this is where much of the capital and running cost is borne.

If mobile, vehicle based cameras were used this would add complexities around tracking the mobile cameras themselves to ensure location and times were 'stamped' for the enforcement images. In addition there would be vehicle purchasing and running costs as well as driver and/or camera operator staff costs.

eRUC OBU in NZ use GNSS technology. How does eRUC and congestion charging compare?

- RUC is a distance based charge only and has no location component. A progressive congestion charging scheme utilises journey time and location.
- eRUC OBU replace mechanical hubodometers on heavy vehicles. OBU on light vehicles are only used for RUC licence display and to provide other value added services. The vehicle odometer is the legal distance measuring device for light vehicles not the OBU.
- The eRUC hardware is an appoved distance recording device – it is not approved for location services.
- eRUC OBU distance is primarily measured using a physical connection to the vehicle odometer/speed sensor as required by the NZTA ERUC Code of Practice. GNSS location is only utilised for RUC refund applications for distance travelled off road or on private roads. The refund process is manual.
- High eRUC operating and capital costs are borne by the transport operator due to the additional business value derived from location based services and the opportunity for easy claiming of off-road refunds.
- eRUC enforcement is performed manually through the use of an NZTA audit team and the Police commercial vehicle inspection unit. To enforce the distance based RUC system, these roadside and back office teams manually inspect vehicle and driver records, log books, manifests, service records, COF/WOF records and RUC licence purchase history. This method of enforcement would not be cost effective or logistically feasible for a congestion scheme.
- Transport operators that use a GNSS OBU can mitigate the driver's privacy concerns by sighting the benefits from improved health and safety of employees within their place of work (the vehicle). This argument would not apply to light vehicles within a congestion charging context and so citizens will raise legitimate concerns about their privacy protection and government tracking.
- eRUC OBUs are not required to offer evidential grade recording of location.

GNSS technology is planned to be rolled out in Singapore for use in their congestion charging scheme. Why not use the same technology here?

Singapore will still continue to use ANPR gantries for enforcement. Tag and beacon technology will still be used for vehicle charge point identification. GNSS is not being used to calculate or generate the charge so in the short to medium term this jurisdiction is not equivalent to a pure GNSS congestion charging scheme.

The addition of GNSS capability is planned to be used for the collection of real time traffic information and potentially the offering of value added services such as usage based insurance. In the future it is likely that Singapore will transition to using the GNSS capable OBU for distance based road charging. This can be done by utilising the existing ANPR and tag and beacon network as a fall back if needed.

Ride sharing apps like Uber and Zoomy use a smartphone for distance, location and time based passenger journey charges. Why not use a similar style smartphone app for congestion charging?

When a ride sharing trip is undertaken the driver and passenger both run apps to ensure the correct fare is calculated and charged. The passenger app is used primarily for booking and account management. The driver is incentivised to ensure their app is operational so they receive their trip payment. If the passenger turned off their smartphone the fare would still be charged since the driver app is running. The redundancy built into the system ensures correct and trusted charging. This redundancy is not achievable for congestion charging as the vehicle user could simply turn off their phone and no charge would be incurred. Additional enforcement through ANPR would be required for this system to work.

Is an OBU really that expensive?

Estimates are $NZ180-$NZ250 for the OBU and $10 / month service fee. This is in line with charges for Belgium truck OBUs which cost €135 (~$NZ220). This does not include the monthly *rental* fee.

Since no consumer product currently exists to meet the requirements of a large scale congestion charging scheme significant upfront costs would be incurred by the supplier to recover R&D, design, testing, manufacturing, warranty, distribution, installation, support and technical risk. Ongoing OBU fees include on-going transmission, mapping and data processing fees. When added to the costs of ANPR enforcement services, these costs will represent a significant percentage of revenues collected.

Can we just use smartphones to implement a congestion charging scheme?

No because not every person has a smartphone and forcing them to buy one is outside of the scheme mandate. Smartphones provide a great option for user account management functions. In the future smartphones could be used on a voluntary opt-in basis to pilot distance and locations based schemes. There are also a myriad of technical, operational and legal issues to resolve before a smartphone could be deployed.

Could a day pass be used to solve the problem for infrequent travel into the congestion region?

Yes if widespread ANPR technology was used for enforcement. If widespread ANPR was available however there would be limited advantage of the GNSS scheme to begin with. It is also worth considering the sheer scale of day passes that would be required. A recent C40 update on the Stockholm scheme found 25% of Sweden's unique vehicles visited Stockholm at least annually representing around 1.25m unique vehicles p.a. As Stockholm's population of 2m represents 20% of Swedish population – pro rata for NZ infers unique out-of-town vehicles for Auckland (who may make multiple trips) to the relatively small Stockholm scheme could number around 250,000 p.a; or roughly 1,000 per day.

Text messaging is cheap, why are the data charges for OBU so high?

OBU data charges are actually quite reasonable at around $10 / month. This includes data and connection charges (mapping and other licence fees should also be considered). If we assume you could communicate all the daily trip data and charge data via 3 text messages per day, and a text message costs 12c, even this would add up to over $10 / month. This does not however take into account the transmission reliability and technical complexities with using text messages rather than secure internet data protocols. Lastly, firmware and mapping updates would not be possible via text message.