PROJECT NO: 3-023

Frictionless ticketing for Public Transport

July 2022

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LA TROBE UNIVERSITY | Centre for Technology Infusion

List of acronyms and abbreviations

3GPP	3rd Generation Partnership Project
AFDO	Australian Federation of Disability Organisations
AoA	Angle-of-Arrival
AoD	Angle of Departure
AR	Augmented reality
BIBO	Be In Be Out
BICO	Be In, Check out
BLE	Bluetooth Low Energy
CAPEX	Capital Expenditures
CIBO	Check In Be OUT
CTI	Centre for Technology Infusion
DIRTDC	Department of Infrastructure Regional Development and Communication
FCC	Federal Communications Commission
FPGAs	Field-Programmable Gate Arrays
FTM	Fine-Time-Measurement
GNSS	global navigation satellite system
HF	High frequency
IoT	Internet of Things
iSims	Integrated SIM
LF	Low frequency
Maas	Mobility as a Service
MEC	Multi-access edge computing
MIMO	Multiple-Input Multiple-Output
MTA	Metropolitan Transit Authority
MVP	Minimum Viable Product
NFC	Near Field Communication
NR	New radio
PDCN	Physical Disability Council of NSW
PWD	People with Disability
RF	Radio frequency
RFID	Radio-frequency identification
RSS	Received Signal Strength
RSSI	Received Signal Strength Indicator
RTLS	Real-time locating system
RTT(1)	Return Travel Time
RTT(2)	Round-Trip-Timing
SBAS	Space Based Augmentation System
SLAM	Simultaneous Location and Mapping
TG	Task Groups
ToF	Time-of-Flight
UHF	Ultra-high frequency
UWB	Ultra-wide band
WiWo	Walk-in/Walk-out

1. Introduction: Frictionless Ticketing Technologies

1.1 Purpose of the research program

Transport for New South Wales (Transport) has partnered with iMOVE and La Trobe's Centre for Technology Infusion (CTI) to evaluate emerging technology options that can deliver Frictionless Ticketing. This project has the primary goal of exploring which of these technologies can reduce friction for People with Disability (PWD).

Public Transport should be accessible to everyone, but the reality is that many barriers still exist. This project seeks to address one such barrier. Many customers with disability face barriers while accessing and using Transport's ticketing system when travelling on the network. Transport, with its vision for future transport development, would like to make the experience 'frictionless'. 'Frictionless' ticketing means that public transport can be used with little or, ideally, no effort, as per the well the known example of Amazon stores in the USA, where customers can pick up products and just leave, paying automatically. Likewise, for public transport, the end-user can simply walk-through gates that automatically open or walk onto platforms and be issued with a ticket automatically, without the need to tap on and off. This project evaluates which technologies should be prioritised. The mobility industry uses Be In Be Out (BIBO) and other models (CIBO, Check In Be Out; BICO, Be In Check Out) to describe variants of ticketing systems. Be In Be Out is the term used for a truly frictionless ticketing experience where customers are automatically and instantly issued with a ticket without having to do anything at that particular moment.

There are several technology options that can deliver automatic capture of entry and exit of transport users on or off the platform or vehicle. iMOVE and CTI at La Trobe University have been contracted by Transport to undertake a research program to explore new and emerging technologies that can offer a true frictionless ticketing experience across multiple modes, with a particular focus on PWD.

The research outcome of this project was to clarify the key strengths and challenges of new and emerging frictionless ticketing technologies. As a result of this research program, Transport wants to understand implications for research trials that will assess how frictionless ticketing propositions can enhance the public transport customer experience.

1.2 Activities: Research Methodology

To do that, we followed a mixed method approach that set out to:

1. Assess the significance of Frictionless Ticketing
2. Review the current state of Frictionless Ticketing Technologies: a global literature and industry scan
3. Develop a technology evaluation framework through stakeholder engagement
4. Prioritise technology options by means of a gap analysis
5. Identify legal and regulatory barriers
6. Develop a test/trial plan for the selected technologies

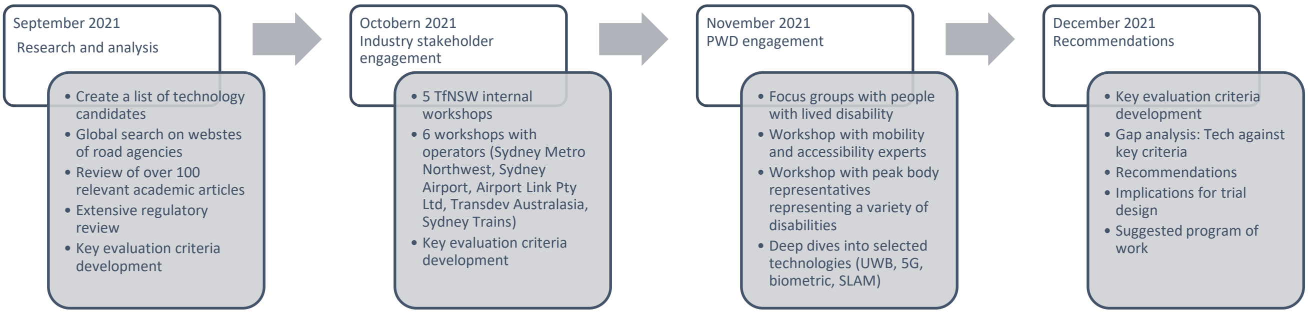


Figure 1. Project activities overview

Project activities

Starting in September 2021 and reporting in December 2021, CTI undertook the activities as per (Figure 1). Stakeholder engagement was a major component of the project.

CTI, with the assistance of the Physical Disability Council of NSW (PDCN) and the Australian Federation of Disability Organisations (AFDO), undertook a series of four online focus groups and consultations with people with disability, peak Disabled Peoples Organisations and experts with lived experience in the public transport field.

Ethics approval was obtained, and all participants were provided with an information statement, an information session about the project, advice on how they could manage any complaints regarding their participation, or withdrawal of consent and required completed consent documentation prior to participation.

Prior to the focus groups and peak and expert consultation sessions, two 1.5-hour information sessions were run to brief participants on both the emerging technologies in this arena, and to provide an overview of the function of the four frictionless ticketing solutions that would be discussed in the secondary consultations.

Two 2-hour focus groups were then conducted online (via Zoom) for people with disabilities, with participants representing physical, cognitive, psychosocial and sensory (vision) disabilities. A total of 12 persons took part over the two sessions and were recruited through the Australian Federation of Disability Organisation’s member base. Half of the participants reside in NSW, the other half in VIC. The range of disabilities included Physical disability, uses mobility aid, MS, Mobility impaired, wheelchair user, blind, acquired Brain Injury, Autism, Blind and Guide Dog user and one person that was blind and had poor cognitive abilities.

A peak body consultation session (also conducted online via Zoom and 2-hours in duration) was conducted with 13 representatives from the following 11 organisations:

- Blind Citizens Australia
- Deaf Society
- Deafness Forum
- Guide Dogs NSW ACT
- NSW Council for Intellectual Disability
- Paraquad
- People with Disability Australia
- Physical Disability NSW
- Spinal Cord Injuries Australia
- Stroke Recovery Association
- Vision Australia

The final consultation was undertaken with participants with lived experience, considered experts in the field of public transport. This session was conducted online via Zoom and ran for 1.5 hours duration and included 7 participants with physical, cognitive and sensory (vision) disabilities.

Engagement with operators

Six online workshops with transport operators and customer service providers with 14 participants in total, representing a variety of transport sectors including Ferry, Metro, Bus and Train provided their feedback and opinions on the suggested technology. Each consultation was conducted online via Zoom and ran for 1 – 1.5 hours for each session. Senior executives responsible for operations or customer experience staff from the following companies participated:

1. Airport Link – Sydney's Airport Train
2. Transdev Australasia
3. Sydney Metro
4. Sydney Trains
5. Transdev, operator of Sydney Ferries

We also conducted an extensive regulatory review, reviewed transport operator websites from around the world as well as looked at many academic publications.

1.3 This report

For reasons of readability, the main report covers a summary of the key findings and recommendations which are substantiated in the appendices. The appendices provide detail about the global search for technologies and best practices, the stakeholder consultations and most importantly, the requirements of PWD regarding ticketing and public transport.

Appendix 1: Technology review
Appendix 2: Stakeholder engagement
Appendix 3: Regulatory review
Appendix 4: Technical literature overview

“My preferred option would be the phone option. We're so used to carrying our phones with us all the time for QR codes and all those sorts of things, it's always by my side and it would be the simplest.” (Source: Focus group)

“I have schizophrenia, which affects my memory as well. So, for me, the smartphone, I thought that was a good idea because I use it every day and that's convenient.” (Source: Focus group)

“I think my first preference would also be the token, just simply because it's specific and separate to transport and everything else seems to be getting lumped on to our phones. I'm glad you clarified about saying you don't need to wave it or anything because when I'm having coordination issues, that would certainly be an issue to be trying to undo a phone and all of that sort of stuff, but I think just to be able to have a token that's a case of yes, this is just for public transport and nothing else.” (Source: Focus group)

“A tag for a guide dog harness would be preferrable. Guide dogs are able to travel everywhere their owner goes.” (Source: Focus group)

“My preference would be an industrial strength token that I could just put on a chain around my neck. And it just wouldn't come off, except maybe in you know the public pool or something with the chlorine would destroy it.”

2. Findings

2.1. Frictionless Ticketing impacts a significant segment and is key to service improvements

In September 2021 - approximately 16,000 concession cards were active, with demand for them being much higher; 60,000 people had requested one. While no doubt that number is inflated by the appeal of free travel, for PWD that do not meet the concession card criteria, tapping on and off can still pose a significant challenge. For instance, for people with a mental or physical disability, using public transport can be a stressful experience, and concerns about having the right ticket ready and finding access to the platform adds to this stress. In addition, there were 37,000 active companion cardholders who travel with PWD to help them during their journey. Note that there are more companions than concession cards as PWD do not always have the same person helping them. From the beginning of 2021 to September of the same year, 152 problems were reported to the customer services team about concession cards. The nature of these problems was quite serious – in many cases the issue prevented the PWD from traveling on public transport. Lost cards are a frequent reason for making an inquiry as are late replacements, expired cards, and making updates to cards

> *Caller states it's more than 6 weeks he is travelling without an opal card and bus drivers keep asking for opal card in front of other passengers. Caller states this is very embarrassing for him but there is nothing he can do about it. (Source: Transport CS)*

> *Caller phoned as he holds a Vision Impaired Pass. Caller received a letter to go online and update his details, however, he is unable to do this. (Source: Transport CS)*

From an operators' point of view, frictionless ticketing is important as it is related to two core aspects: the customer experience and efficiency of operation. For example, the absence of Frictionless Ticketing requires inefficient gate management. As PWD who are using concession cards can't open platform gates, gates are required to be manned, closely monitored, or left open. Having staff standing at a gate, waiting to assist a person with a disability when they present themselves is not an effective use of time and resources.

Frictionless ticketing and the data it can generate, offers attractive benefits to operators. For example, the possibility of being pre-warned on the arrival by way of a smart ticket, or, staff being aware that a PWD is at the platform or in a vehicle could improve the security procedures and assistance can be offered quicker if the presence and position of the PWD is known. Moreover, transport operators subscribe to the view that equal access means independent access and autonomy. Lastly, operators would like to see that everyone has 'frictionless access' not just PWD. As noted in the operator's consultation: *"Like a shop with its doors open – it is just more welcoming".*

The importance of frictionless ticketing for PWD can perhaps best be illustrated with the quotes below, from focus group participants. Participating in public life is already a challenge for many PWD and public transport, as crucial as it is for them, is often a stressful experience.

> *"It creates more independence. Yes, so any arguments that they could use, anything that's going to make our lives easier." (Source: Focus group)*

> *"Giving back mobility and independence to a person with a physical disability (not having to ask for assistance)." (Source: Focus group)*

> *"Independence. You need someone to open the gate for you at the moment, you won't need that." (Source: Focus group)*

> *"So, anything that Transport for New South Wales can do that assists us to be able to access the community can really mean the difference between being part of the community or not." (Source: Focus group)*

The significance of the issue is underlined by the Department of Infrastructure Regional Development and Communication (DITRDC). DITRDC is currently (as of 15/03/2022) soliciting feedback on fare systems. It has recognized the significance of the issue and in March 2022 DIRDC released 'Reforms of the Disability Standards for Accessible Public Transport 2002, Stage 2 Consultation Regulation Impact Statement' (Department of Infrastructure, Transport, Regional Development and Communications, 2022), where fare systems are listed twice (see Table 1).

Table 1. Reform area's summary (fare systems)

Reform area	Issue
23. Accessible fare system elements	The Transport Standards do not adequately cover or support existing or future technologies used in fare payment and validation. As a result, current fare system requirements are not fit-for-purpose and customers with disabilities may be exposed to inaccessible or inconsistent fare systems. There is an opportunity to ensure that accessibility requirements for fare payment and validation systems are reflective of existing and future digital technologies and ensure that accessible fare payment options are equal in cost with other options.
29. Location of Fare System Elements	There is limited clarity regarding the specific location of fare system elements, which may lead to an inconsistent and potentially inaccessible travel experience that prevents some people travelling independently. There is an opportunity to clarify the accessibility requirements for the location of fare system elements by simplifying and co-locating these requirements in a new section.

The Consultation Regulation Impact Statement further states that it is proposed that, the Transport Standards would include the following new requirements:

- Fare systems must not require actions from passengers with disabilities that exceed the requirements for other passengers.
- For passengers with disabilities who have difficulties with standard fare systems, operators and providers must offer a form of payment that meets equivalent access principles. Forms of payment offered:
  - Must not incur a surcharge for a device or be charged at a higher rate than other fare payment options.
  - Should facilitate independent access through fare gates.

Among the qualitative benefits the consultation paper lists:

1. Amenity: Providing consistent standards across all fare systems at public transport sites will improve ease of use when purchasing fares for both existing public transport users with a disability and users without a disability.
2. Accessibility: Providing equivalent access for users with disability can allow new users of public transport with disability to purchase fares with accessible options and potentially increase use of public transport by people with disability. This option also includes accessibility requirements for vision-related and hearing-related disabilities.
3. Other benefits: Other benefits of this reform include increased optionality, enhanced independence and inclusion, greater sense of connection to community and place, improved access to services, increased opportunities for education and employment

This report contains concrete guidelines that can contribute to DITRDC's Disability Standards for Accessible Public Transport and the Whole Journey Guidelines.

2.2 Global best practices: Frictionless ticketing initiatives are just emerging

A global review of transport agency websites, payment seminars, commercial and academic literature has shown that true frictionless ticketing is still an emerging use case. We have not been able to identify an operator that has deployed frictionless ticketing across all modalities.

Facial recognition, Korea: Public transportation in urban cities has been one of the central places of anxiety and fear amidst the COVID-19 era, since physical contact with other people is unavoidable, especially during rush hours. Korea Smart Card says it is trying to reduce these concerns with a “face recognition payment system” that eliminates the need to tap on with a card or a phone. The new payment system has been introduced at 22 gates in 13 stations on the Ui-Sinsol line, starting off with a pilot operation for employees and officials of designated stations. During the pilot period, T-Money plans to speed up its commercialisation by tracking and improving the actual payment speed of facial recognition payments. The company takes pride in the fact that the system accurately recognises users without them having to lower their masks. T-money’s face recognition payment will be available in the future to users who follow the three steps: (1) downloading the T-money mobile application, (2) registering the user’s face through the camera, (3) linking it to the user’s payment method. The payment will be made automatically when passengers go through the gate while looking at the screen (Hae-yeon, 2021).

Facial recognition, Japan: Bus passengers in Japan are taking part in a pilot of self-driving buses equipped with facial recognition technology which enables them to pay for their tickets as they board using a ‘face pass’ system. Passengers have their face scanned and registered beforehand so that their account gets charged automatically once their face is detected boarding a bus. The Osaka Metro began testing facial recognition gates on the city’s subway in December 2019. The Japanese newspaper reports that the system has been implemented at four stations of the rapid transit system. The goal is to install the facial recognition system at all metro stations in Osaka by 2024. Osaka Metro says one advantage of the facial recognition system is “the fact that passengers with large luggage will be able to pass gates simply by showing their faces instead of looking for tickets. According to Osaka Metro, some challenges remain, such as correctly identifying a face “covered from the nose down with a face mask” (Philips, 2020).

East Japan Railway Co. is looking to introduce "walk-through" ticket gates at stations that will enable passengers to access gates via a specialised smartphone application. Passengers will not have to produce their prepaid commuter passes to the system. Under the envisaged system, millimetre waves will be emitted from an antenna placed on the ceiling above a gate that will open once data sent from the passenger's smartphone application has been received. The company has worked to limit the emission of millimetre waves. The two-thousandths of a second needed for the process is the same as the signalling speed of the next-generation ultrafast 5G communications networks (NEWS, 2019)

Facial recognition, China: China is at the forefront of facial recognition technology. Since 2019, payment based on facial recognition technology has been operating in the Zhengzhou metro. Similar systems are also implemented in the metros of other major cities of the Middle Kingdom, including Shanghai, Nanjing and Shenzhen. In addition to the metro, the face-to-face payment service is being implemented everywhere on China's land transport. At the entrance to the vehicle interior, devices equipped with facial recognition technology are installed. The scanner identifies the person when boarding, after which the money for the trip is automatically debited from the bank card linked to the passenger's personal account in the transport application. Beijing is now considering the introduction of “bio-recognition technology” to its metro network. The city will look to implement palm scanners and facial recognition scanners which would supposedly help increase efficiency and decrease gridlock in key stations during rush hour (Recfaces, 2021).

Ultra-wide band (UWB), New York, USA: Frictionless ticketing is an anticipated use-case for UWB, but we have not found trials or publications about UWB and ticketing. We have, however, found that The New York Metropolitan Transit Authority (MTA) has awarded Humatics and Siemens a $US 14m contract to develop an interoperable UWB specification, building on the success of a 2019 pilot project which determined the effectiveness of using UWB in conjunction with Communication Based Train Control. To provide precise speed and position, the Humatics Rail

Navigation System UWB beacons are installed along the trackside five to nine feet off the ground and within the enclosed bonnet of the train. Humatics UWB beacons on the train and on the wayside communicate using a technique called Two Way Time of Flight, to calculate ranges, or distances, which are delivered to the Humatics onboard computer. Humatics' sensor fusion technology within the onboard computer uses AI algorithms to then combine ranges with train acceleration data, providing an output of precise location, position, and speed. Humatics real-time location data can then be integrated with a train control computer and uploaded onto the cloud-enabled applications beyond train control, continuous analysis, monitoring, and algorithm improvement. (Railpage, 2021)

Bluetooth, Germany: Stadtwerke Osnabrück, the public agency that manages utilities, public infrastructure and transport for the city of Osnabrück, launched a check-in/be-out (CIBO) system with its YANiQ app, following a months-long pilot program. The much larger German city of Hamburg plans to launch a CIBO system later in 2022. Both are using a system in which riders check in with a swipe in the app, then simply leave the transit vehicle at the end of their trip. (Smith, 2021)

Bluetooth, Portugal: A similar system launched in 2018 by the Portuguese ticketing agency, TIP, that runs ticketing for 19 public bus, tram and train operators serving Porto, Portugal's second largest city, uses a hybrid near field communication (NFC) check-in/Bluetooth be-out system for its Anda mobile app. For the YANiQ app, a pair of Bluetooth low-energy beacons aboard each bus, combined with GPS and motion-sensing data from the passenger's smartphones, tracks the passenger's journey. The back end of the system stores that information and calculates the best available ticket pricing for each passenger at the end of the week, and passengers can view trip and pricing information in the application at any time. Furthermore, like other CIBO systems, YANiQ monitors passengers to prevent ticketing fraud, such as passengers turning off their smartphones' Bluetooth connection mid-trip to trick the system into charging a lower fare. If Bluetooth is disabled or the mobile connection is lost, the system is still able to collect enough data about the device's location to calculate fares for the trip. The system backs up the Bluetooth low energy (BLE) beacons' data with GPS information from the user's smartphone, as well as combining it with motion-tracking information from the phone. And although the application can only send the passenger's location information to the system's back-end servers when mobile data is available, if passengers are in an area without a cell phone signal, such as a tunnel, the application stores location-related data and transmits it to the system's back-end servers when the signal is restored. (Balaban, 2021)

Four key options emerged for the principal device that is used to implement frictionless ticketing of which the high-level architecture is depicted in Figure 2.

The top hardware layer shows the devices and the technologies that can be used to verify and authenticate the passenger. The second layer depicts how the start, and the end of the trip are determined, which, in the case of the phone is done with the same device at the top level. Data is then de-identified or 'tokenised', before being processed by the middleware, back-end applications and data warehouses to enable fare calculation, payment and analysis. Phone-app based applications may have the advantage that authentication and verification take place on 'infrastructure' that is owned by the passenger.

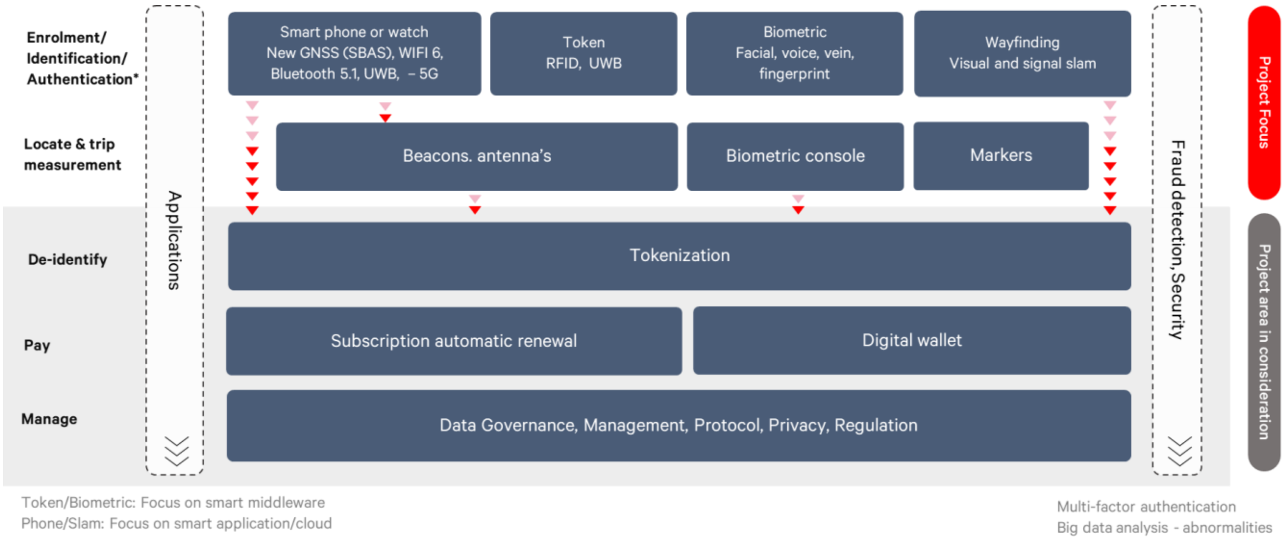


Figure 2.Frictionless Ticketing Technology Framework (Source: CTI)

“The idea of facial recognition, I think that would be absolutely ideal, that I can just turn up and use the service without having any additional steps or any of those planning issues to worry about. I think that would just be absolutely perfect and I know that that would really benefit my kids because they have my youngest son has an intellectual disability and is autistic and he has massive anxiety, so he does a lot, as a part of his anxiety he tries to make everything perfect and does a lot of planning, which creates a lot of stress and it becomes this cycle for him.”
(Source: Focus Group, Intellectually disabled)

“If we could use facial recognition only for one gate and leave the rest for everyone else, so it is optional to use it, would that be good? Yes, that would be really good. If we have split the section half, maybe people who do not prefer facial recognition and go to one of the given sections? I guess we will always get resistance and once they see how the world moves and get onboard, they will probably understand soon after. I am all for frictionless ticketing and I believe this is the future rather than trying to catch up with the rest of the world. The key points for us are fare evasion, throughput and the customer experience.” (Source: Operator workshop)

2.3. A technology evaluation framework through stakeholder engagement

2.3.1 Transport: Deployment across various gate situations

In collaboration with Transport, we have developed an evaluation framework, with requirements for frictionless ticketing technologies to meet. These include:

- Works in gated and ungated locations
- Works indoors, underground and outdoors
- Can detect entry into a vehicle (as opposed to walking by)
- Generates no false positives (e.g., signals through walls, or for outgoing/disembarking users)
- Executes gate opening and closing ‘just in time’ for gated solutions (only for the first in line)

One of the key challenges is to provide a solution for indoor gated stations; today’s technologies are unlikely to provide the accuracy, resilience and speed required to reliably deliver on that use-case. For example, radio-frequency identification (RFID) signals can easily be blocked by metal (e.g., lunchbox) or other objects. Bluetooth will be challenged to deliver accurate positioning, which is required for instance to distinguish the first user in line vs. the second in line in front of a gate, 4G/GPS doesn’t work reliably indoors and isn’t accurate enough outdoors.

Other evaluation factors were use-case specific factors; end user requirements; technical performance criteria; business case metrics; planning and operational factors; Mobility as a Service (Maas) criteria; and legal and regulatory requirements.

2.3.2 Operators requirements

Overall, operators have a keen interest in frictionless ticketing as it improves their services and will likely increase public transport usage. Furthermore, it can help make their operations more efficient. There is also a broad awareness of the need for inclusivity, but in order to be truly inclusive, frictionless ticketing must be absolutely flawless and work for everyone, not only for PWD. Table 2. provides a summary of the operator requirements, with a notable request that the effect of fare evasion needs to be investigated; the expectation is that fare evasion may increase. Besides being reliable and with very low maintenance, easy sign up for one-off or new customers and the management of fare evasion are other priorities.

Table 2. Operator requirements

Factor	Operator’s summary
No gates	Welcoming: like an open shop front. “Yes, I can see a world where we are not mechanically separated…”
Lower friction	The essence of non-discrimination legislation is equality. Having to look for your phone or card is always a little stressful, in particular when you are rushing to make it to a particular train.
Accessibility and inclusion	Recognition that public transport for PWD is stressful – anything that can help is welcome. Will need extensive introduction, staff and user training.
Usability	First criterium is the usability – it simply needs to work well – not demand extra attention or servicing. It should be easy for first time visitors (e.g., arrivals to the airport), those using casual tickets, companion cardholders, groups, and minors
Direct efficiency (throughput)	It should benefit everyone. Saving 1 or 2 or 3 seconds a passenger, it adds up.
Indirect efficiency	Time that is freed by not servicing the gates, and the efficiencies gained, can be used for higher added value activities.
Throughput management	Sometimes (e.g., New Year's Eve) gates help to manage traffic and prevent too many people being on the platform.

Data	Operators currently have no idea about the number and type of people with disability that use their network – but would like to have that information. Transport will also need to prove that the system is improving the journey whilst maintaining privacy.
Fare evasion control	The absence of gates may increase or reduce fare evasion; however, this requires further research. Can CCTV cameras be used to spot repeat offenders?
Service improvements	Wayfinding Prior notice of ramp requirement A panic button, being able to locate people with disability Recognising people with a hidden disability
Challenge	There are still blackspots at several locations in NSW sometimes due to security reasons, not a lack of coverage

Note that Operators are neutral when it comes to which technology is used granted it meets the above criteria.

2.3.3 People with Disability requirements and expectations

To solicit informed feedback from PWD, prior to the discussions with PWD we held information sessions to explain what frictionless ticketing is, presented an overview of technology trends for background understanding and the four options to consider for the concept of *'tap on and tap off for PWD without having to do anything' (*Table 3*).*

Table 3. Option for frictionless ticketing

1. Smart phone	2. Wearable token	3. Biometrics	4. Integration with assistive technologies
An app on your smart phone or smart watch	A small device, like a key chain or wristband (it can take many forms)	A device on the train station or bus stop that can read a biometric characteristic (face, fingerprint, voice, etc.)	A body camera or a phone app for people with disability that 'looks out' for you and guides you

One solution does not fit all

It quickly became clear that standard marketing practices used for product development projects such as these do not apply. These standard practices are usually about identifying the largest common denominator in order to focus activities and investments on the biggest 'bang for buck'. In this case however, each disability has its unique requirements and if they are not accommodated, it could mean that the group is excluded from Public Transport.

Consequently, one solution does not fit all. Some PWD rely on their phone and would welcome the extra functionality:

> *"My preferred option would be the phone option. We're so used to carrying our phones with us all the time for QR codes and all those sorts of things, it's always by my side and it would be the simplest."*

> *"I have schizophrenia, which affects my memory as well. So, for me, the smartphone, I thought that was a good idea because I use it every day and that's convenient."*

However, some people like the set and forget nature of a token.

> *"I think my first preference would also be the token, just simply because it's specific and separate to transport and everything else seems to be getting lumped on to our phones and I suppose the other I'm glad you clarified about saying you don't need to wave it or anything because when I'm having coordination issues, that would certainly be an issue to be trying to undo a phone and all of that sort*

of stuff, but I think just to be able to have a token that's a case of yes, this is just for public transport and nothing else."

"A tag for a guide dog harness would be preferrable. Guide dogs are able to travel everywhere their owner goes."

"My preference would be an industrial strength token that I could just put on a chain around my neck. And it just wouldn't come off, except maybe in you know the public pool or something with the chlorine would destroy it."

Biometrics was perceived to be the most convenient, in that users do not require any form of technology with them, other than themselves. It was, however also the most controversial with PWD, as many participants were not comfortable with a public entity gaining their biometric data.

"So, the idea of having somewhere where you actually don't have to do anything, that just recognises your face or some other method would be really beneficial, that we could just turn up and use the service that we need to use without needing to do any of that planning and remembering and steps with technology."

Lastly, people familiar with wayfinding apps did find the option of integrated ticketing appealing:

"Lidar is also a good option because it will guide the person to the gate and assist them to navigate getting on the train etc. An app that syncs to an Apple watch would be good."

For people that have a disability preventing them from using a phone, a token is the preferred solution. For PWD who can handle a phone, the phone tends to become even more essential, and they would welcome the option that the phone becomes their ticketing device. Biometrics is preferred by PWD who struggle with due to intellectual disabilities. The integration with wayfinding apps also had appeal for the Vision Impaired.

Our recommendation is consequently, that these four options should be explored and that no option can be disregarded at this stage. These options include a phone app, a token, biometrics and integration with a wayfinding app. Each option serves its own PWD customer segment. We recommend quantitative research to estimate the size of each segment.

Easy and reliable

PWD are positively pre-dispositioned to frictionless ticketing technology if a ticketing system is easy and provides peace of mind (reference), however, they are also sceptical. Technology doesn't always deliver on its promise. Today, there are still quite a few locations where even something as basic as a phone doesn't work. Hence, PWD emphasise that there must be a (human) backup.

Table 4 summarises the findings on requirements for PWD with regards to frictionless ticketing. For a full understanding of the pros and cons outlined in the PWD consultation session we encourage the reader to refer to Appendix 2.

Table 4. Key factors and findings from PWD Consultations for frictionless technologies

Key factors	Universal design principles	Implication/finding
Handsfree and easy	Low Physical (and mental) effort	Embraced by most – if indeed no physical effort *(and very low mental effort is required)*
	Equitable Use	Facial recognition is the most 'equitable' – it works for everyone. The token can be a set and forget function too for almost everyone (e.g., some with cognitive disabilities say that a token is also too much), but wayfinding, and the phone option will not suit everyone.

	Flexibility in Use	No one solution fits all. A token could come in various forms: a credit card, a clip for the guide dog's harness, a necklace. The phone will need to accommodate various accessibility modes (voice, gesture).
	Simple and Intuitive Use	Fit to user's experience, knowledge, language skills, or concentration level. Particularly important for the phone app, but also for the other solutions. Policy and registration are part of simplicity: e.g., companion cards and family members.
	Perceptible Information	Apps that are mentioned for their good design are: FROG id, Natureblitz, Bendigo Bank App, Apple feedback form (tick box only).
Peace of Mind	Tolerance for Error	Provide fail safe features. Redundancy - human assistance - needs to be in place. Provide confirmation of a ticket and the warnings of hazards and errors. Discourage unconscious action in tasks that require vigilance.
	Size and Space for Approach and Use	Placemaking consistency: Guide and assistance dogs can be trained to go to a certain place for facial recognition – for instance the accessible gate or the right side of the platform entry.
	Additional factors: Added value	PWD welcome 'added value' options: better management of ramps, certainty about priority seating, and being able to be located quickly in case of emergency are a few examples.
	Protected from abuse: Not being over charged	PWD are often in vulnerable positions when it comes to making payments – they'd appreciate the opportunity to check their trips and charges. PWD with concession cards (free travel) are now worried about this being an 'excuse' to start charging.

2.3.4 Frictionless end-to-end user experience

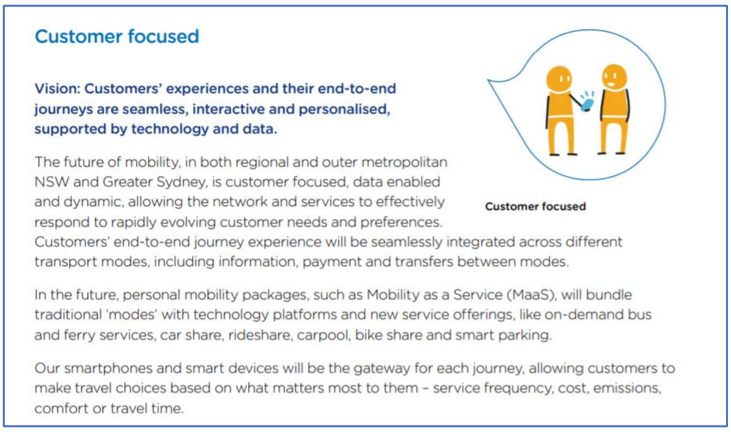
Frictionless ticketing is only as 'frictionless' as the weakest link in the end-to-end process. In other words, unless *all* aspects of the ticketing process are addressed, ticketing is not really frictionless. There are a number of issues for Transport to address in the end-to-end ticketing experience. Table 5 details such issues.

Table 5. Factors to be considered for PWD end-to-end journey

Activity end-to-end user experience	PWD requirements
Registration	Ability to choose a registration option to suit needs (online, in person, via phone)
	Online via previously registered services (Service NSW, Google, Apple, MyGov)
	In person – Post Office, Telstra shop, local council office, Service NSW centre
	Phone assistance
	Previous recognition of 100 points ID
	Ability to include disability specific requirements (e.g., to automate assistance on any journey)
Education	Education of any new system and piloting to test functionality
Assistance	Help function when needed (button or intercom)
	Link to human assistance
Automation	Automatically registers need for assistance (ramp for boarding)
	No physical interaction needed during journey
Notification	Provide notice of changes to trip
	Advise if on wrong journey/mode
	Confirmation of payment (vibration/light/sound)
Payment	Online account to track payment
	Ability to split payments between personal and work use
	Accessible top up stations
	Option suitable for those with limited funds/financial management
Integration	With transport apps
	With assistive technologies
Frictionless Ticketing Technology	Inclusive solution preferred: works for all, not just PWD
	No 'lag'
	Easy ability to cancel (card/token) when lost
	Elimination of physical 'gates'
	Fail safes when one technology doesn't work
Flexibility/Choice	Provide personal choice
	Used by those with and without disability

Beyond 'just moving them'

Frictionless ticketing offers a very good opportunity to deliver on Transport's vison, which is to 'enhance customers lives, not just moving them' (Figure 3).


Customer focused

Vision: Customers' experiences and their end-to-end journeys are seamless, interactive and personalised, supported by technology and data.

The future of mobility, in both regional and outer metropolitan NSW and Greater Sydney, is customer focused, data enabled and dynamic, allowing the network and services to effectively respond to rapidly evolving customer needs and preferences. Customers' end-to-end journey experience will be seamlessly integrated across different transport modes, including information, payment and transfers between modes.

In the future, personal mobility packages, such as Mobility as a Service (MaaS), will bundle traditional 'modes' with technology platforms and new service offerings, like on-demand bus and ferry services, car share, rideshare, carpool, bike share and smart parking.

Our smartphones and smart devices will be the gateway for each journey, allowing customers to make travel choices based on what matters most to them – service frequency, cost, emissions, comfort or travel time.

Figure 3. Sourced from Future Transport 2056 – the vision for the next 40 years of transport in NSW

2.3.5 Evaluation framework

Throughout the project we have kept a running list of evaluation criteria that can help to prioritize technologies for frictionless ticketing. The criteria were generated in discussions with Transport, operators, and people with disability. The full list of criteria was ranked (essential vs nice to have) by the project team, leading to the below evaluation framework of essential criteria (Table 6).

Table 6. Evaluation criteria

Technology MVP core tasks, what it needs to do	End user requirements	Ticketing use case specifics	Key technical performance requirements
• Identification • Tokenization/ authentication • Positioning and trip definition • Registration in (begin of ticket); Registration out (end of ticket).	• Reduce friction for PWD • End-to-end user friendly • Easy registration • Redundancy (e.g., access to human support) • Added value/benefits/ personalisation • No or low end-user hurdles to adoption • Scalable to other segments	• Can detect entry in vehicle (as opposed to walking by). Determines with high accuracy which mode of transport had been/is being used • No false positives • Evacuate gate open and close 'just in time' for gated solutions • Work indoor, underground, outdoor (with and without GPS) • Works in all urban and regional areas across NSW • Communicate at points along the journey (not just at the gates) • Facilitate seamless multi-modal journeys	• Technology readiness – now vs. emerging • Certainty/reliability (e.g., interference) • Accurate/ very low error rates • Secure – not easy to forge, clone • Fast, low latency • Low power consumption • Integration legacy system, impact on future system architecture
Business case metrics	**Transport planning/operational**	**MaaS criteria**	**Legal and regulatory requirements**
• Reduce current friction; forgotten cards, physically not being able to tap on or off, not enough credit, or lost cards • Reduce cost of servicing • Scalable • Higher customer satisfaction • Increase penetration, volume, share of trips • Building block towards MaaS and Connected Journeys • Cost effective • Green • Low hurdles from partners and third-party service providers • Work in taxi's, minibuses, mopeds, bike sharing etc • Consider fare evasion ore revenue increase • High feasibility of installation across all use cases • Low maintenance/ Asset Management System (resistant to vandalism)	• Buses with on board validators; ferries with partly gated and partly FLR wharves; rail with staffed and unstaffed stations; rail with gated and ungated stations as well as lifts and escalators; rail with underground stations • Cover fixed and variable route services • Works for casual travellers • Maintain, manage or improve throughput • Capacity to process multiple entries simultaneously • Added value: personalise journey's, signal ramp needed, location of person in distress, identification of hidden disability • Allows performance monitoring and reporting	• Can extend into payment solution for carparks, and other third-party providers • Enable personalised journeys (e.g., automatically open a ramp) • API for third party MaaS service providers	• Meet regulatory requirements and certifications • Meet privacy regulations and Transport Act • Low risk in regard to data governance • Enable fraud detection/ fair evasion check

“Technology can both help and hinder us, where we can grab it and use it, we should, particularly as it gets better. I want to be able to explore on my own, so if technology can do that I would be pleased. Wayfinding would be great.” Source: Focus group)

2.4 Prioritise technology options

To prioritise technology options, we verified the latest developments through literature research and industry scans, and consequently conducted a gap analysis against the technical use case criteria.

2.4.1 Tech developments: Birds Eye View

Frictionless ticketing is only one application in the field of rapidly changing Smart City applications. Information and communication technologies, the proliferation of big data, internet-of-things, and cloud infrastructures are all changing the existing city ecosystems. Harnessing the advancements in these fields can assist cities to become secure, economically efficient, and sustainable, whilst addressing many of the arising urbanisation challenges.

Several technology trends are reaching maturity, enabling the next wave of innovations, including frictionless ticketing. Such technology trends can be seen in Figure 4.

1. Location positioning and time
   - Almost all wireless technologies have developed new protocols and updated hardware in order to deliver accurate indoor and outdoor positioning on demand.
2. Speed/low latency
   - Wireleless technologies are reducing the latency in order to meet future use case requirements.
3. Processing power and miniaturisation of hardware
   - Hardware processing power has been and is still increasing exponentiallly
4. Big data
   - The techniques and methods of Big Data facilitate for instance accurate trip fare calculation and trip optimisation.
5. Low power consumption/battery technology
   - Potential tokens or wearables are required to have a long battery life - especially for PWD - batteries are rapidly improving
6. Encryption, security
   - The need for security has created a whole new industry focusing on the protection and reliability of data that is captured and used by frictionless ticketing systems.

Figure 4. Technology trends (Source CTI)

2.4.2 Frictionless ticketing technology options

The key to delivering frictionless ticketing lies in two core capabilities: accurate and reliable positioning, and low latency or high speed of data communication. A passenger approaching a gate needs to be recognised and have their eligibility to enter verified in a very short period of time so that the gate opens promptly. Accurate positioning is required, for instance to ensure that the gate doesn't open for the next person in line.
Figure 5 illustrates frictionless ticketing using a virtual gate, but the same logic applies to an actual gate which needs to open at the right time for the authorised person only.

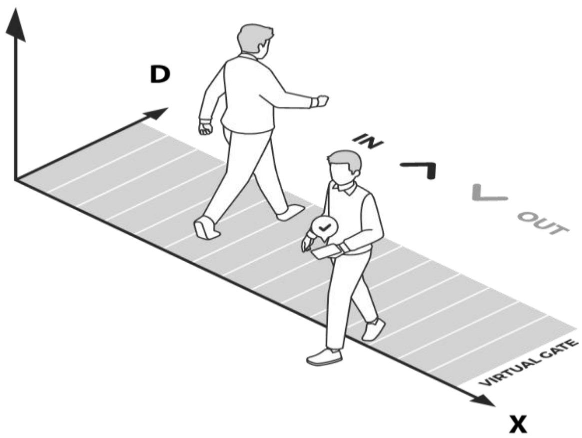


Figure 5. Virtual Gate

Table 7 provides a summary of the status of the key technology candidates for frictionless ticketing. Almost all wireless technologies have rolled out new versions or are developing new releases that accommodate the core needs of low latency and high accuracy in positioning.

Table 7. Technology candidates (Source: CTI Analysis, see appendix 1 and 4 for background)

Technology	Summary overview
Bluetooth 5.1	BLE 4.2 is the low energy version of Bluetooth classic which has many beacons already deployed. Bluetooth 5.1, recently released in 2019, is the future of Bluetooth designed for Real-Time Location System (RTLS) using a mesh-based model. It uses Angle of Arrival (AoA) and Angle of Departure (AoD) for centimetre-level precision.
RFID	RIFD is a well-known technology that is easy to implement. Developments for RFID are focused on novel positioning methods to increase the reliability (meshed approaches to address line of sight issues) and accuracy (by combining for instance inertia data)
Wi-Fi 6	Wi-Fi 6 has improved Fine-Time-Measurement (FTM) which is necessary for Wi-Fi Round-Trip-Timing (RTT). The RTT is a feature added to the IEEE 802.11 protocol by the Task Group mc (TGmc) of the IEEE 802.11. The purpose of Wi-Fi RTT is to allow devices to measure the distance to nearby Wi-Fi routers and determine their indoor location with a precision of 1-2 meters.
GNSS/SBAS	A Satellite-Based Augmentation System (SBAS) called the Southern Positioning Augmentation Network, or SouthPAN. SouthPAN will augment standard positioning capability provided by GPS and Galileo across all Australia and New Zealand, improving the accuracy of positioning from 5-10 metres to 10 centimetres without the need for mobile or internet coverage.
5G	5G New Radio (NR) uses new technologies to provide faster and more accurate positioning than 3G/4G 3rd Generation Partnership Project (3GPP) for compatible devices, even for crowded indoor spaces. 5G releases 16 and 17 will use enhanced Return Travel Time (RTT) for distance measurement and advanced Beam Forming (e.g., Massive- Multiple-Input Multiple-Output (MIMO)) for precise AoA and AoD measurements.
UWB	UWB is a technology for the radio frequency (RF) transmission using 500 MHz with a very wide frequency band (for high throughput), short pulses (for minimal interference), with very low power consumption at short distances. UWB provides precise indoor tracking up to centimetre-level accuracy using Time of Flight (ToF) rather than Received Signal Strength Indicator (RSSI) which is the traditional technique for indoor positioning but is prone to inaccuracies (for instance by people blocking the signal). The broad frequency and small pulses deliver a more reliable method than RSSI.
Biometrics: Facial	Facial recognition is developing towards using less of people's faces, with increased accuracy. Eyes and eye brows alone now generate high levels of accuracy. Though there is considerable discussion in the public domain, by 2024, Mercator forecasts that 66% of smartphone owners will use biometrics for authentication. Currently, Mercator estimates that 41% of smartphone owners are using biometrics. Just a few years ago, in 2019 only 27% of consumers used biometrics to authenticate.
Biometrics: Other	More and more biometric tools and measurements are under development. Apple for instance has patented vein recognition by phone, whereas heart rate patterns collected by Fitbit are being developed into identification metrics.
SLAM	Simultaneous Location and Mapping (SLAM) provides precise positioning in indoor and outdoor environments. A LIDAR sensor scans a 3D map of the environment and in real time determines the position of objects. An application uses position data and time for providing guidance and could be used for issuing tickets. Visual base SLAM uses visual features such as fiducial markers to identify the location and calculate the position in a map. Signal-based SLAM uses Bluetooth and/or Wi-Fi beacons with the help of third-party services and software to precisely calculate positions using RTT and AoA methods.

2.4.3 Gap analysis

We conducted a high-level gap analysis against the technical use case criteria based on literature research, industry scans and expert analysis (see Appendix 1 and 4). Direct comparisons of technologies in this use case – frictionless ticketing - are not available. The tables contain high level evaluation notes with inferences based on available information. Please see 'Appendix 1: Technical review' and 'Appendix 4: Technical literature overview' for the background research. These tables can inform testing programs, indicating the area's where further validation is required.

The two technologies that seem the best fit for purpose are 5G and UWB given their potential to accurately determine position and reliably communicate with low latency.

Minimum viable product (MVP) criteria (Table 8)
All of the options in principle have the potential to deliver the basic tasks.

Table 8. Gap analysis: core functionality. (See Appendix 1 and 4 for background research)

	Use case requirements	Phone - Bluetooth	Phone-5G	Token UWB	Token RFID	Bio Metrics	Wayfinding (SLAM)
MVP core criteria	In principle: Identification, Tokenisation /Authentication	yes	yes	yes	yes	yes	yes
	In principle: Positioning and trip definition	yes	yes	yes	yes	yes	yes
	Capacity to process multiple entries simultaneously (large quantities / high throughput)	Depends on configuration – to be tested	Likely. Depends on configuration – to be tested	Likely, proven in industrial applications.	Proven on tollways with active RFID	High throughput and accuracy in ungated situations?	Likely, as ticketing is hosted by customer device. T

Ticketing use case specific criteria (Table 9)
Looking at use case specific criteria, differences emerge specifically with regards to the ability to function with accuracy and speed in gated and non-gated situations.

Table 9. Gap analysis: use case specific criteria (See Appendix 1 and 4 for background research)

	Use case requirements	Phone - Bluetooth	Phone-5G	Token UWB	Token RFID	Bio Metrics	Wayfinding (SLAM)
Ticketing use case specific	Can detect entry in vehicle (as opposed to walking by).	Yes, by 'pinging' the device at regular intervals	To be tested - dependent on 5G smart phone roll out. Accuracy as claimed should be sufficient	Yes, the accuracy of the distance and the angle can ensure this	Yes, if multiple RFID readers are installed.	yes	Research required
	Execute gate open and close 'just in time' for gated solutions.	Most use cases to date are BIBO, CIBO entry into buses, trains vehicles - rather than gated	yes	Yes, this technology is designed for accuracy	Requires careful configuration. It may be challenging to distinguish between the first and second in the row	yes	Opens gate via the cloud, similar to credit card (requires research on speed)
	Consider gated and non-gated	Bluetooth applications to date focus on buses, not gated platform entries.	To date focus is on gated solutions using mmWave. Non-gated solutions	UWB has large data capacity and high accuracy, non-gated solutions	Both passive and active RFID perform best when there is line of sight	Non-gated capacity to be tested	To be tested

			should not pose a challenge	should not pose a challenge			
	Works indoors and outdoors	Requires virtual fence to make it work indoors and outdoors without high power consumption	Yes, if 5G network is extended indoors	yes	yes	Yes	Mostly proven indoors for small devices (Autonomous vehicles use high data rates and processing capacity
	Works everywhere in NSW - Australia	yes	Depends on Telco's	yes	yes	Yes	Needs reliable, fast Internet connection for end users
	Cover fixed and variable routes, i.e., cannot rely on fixed outdoor infrastructure	Yes, infrastructure can be in vehicle	Yes, infrastructure can be in vehicle	Yes, infrastructure can be in vehicle	Yes, infrastructure can be in vehicle	How would it work in a vehicle?	Research required how best SLAM
	High feasibility of installation across all use cases	yes	yes	yes	yes	Privacy concern	Requires location of gates to be mapped
	Low maintenance/ Asset Management System (also Resistant to vandalism)	Due to low cost of beacons, often left 'out in the open'	Responsibility of Telco	Validation required	Validation required	Visual direct line of sight required	Advantage: no infrastructure required

Technical performance criteria (Table 10)

In terms of assumed technical performance reliability and speed sets the solutions apart.

Table 10. Gap analysis: Key technical performance requirements (See Appendix 1 and 4 for background research)

	Use case requirements	Phone - Bluetooth	Phone-5G	Token UWB	Token RFID	Bio Metrics	Wayfinding (SLAM)
Key technical performance requirements	Technology readiness – now vs. emerging	Ready	Core functionality tested, but no specific use case evidence	Functionality tested, but no specific ticketing use case evidence	Ready	Facial recognition: commercially available in transport.	LiDAR wayfinding is available commercially
	Certainty/ reliability	Depends on configuration, needs testing	Release 16 and 17: Features suggest yes – requires field validation	High	Validation required. Easy to be interfered with or blocked	Needs line of sight. High level or reliability can be achieved. Validation required	No interference, but reliability of LiDAR and positioning to be tested
	Accurate/very low error rates	Depends on configuration, needs testing (large amount of people, line of sight issues)	Release 16 and 17 Features suggest yes – requires field validation	High	Easy to be interfered or blocked, otherwise can be made fairly accurate	Very accurate indoors and outdoors, but validation is required to test circumstances (light, rain, etc.)	Indoors is very accurate, outdoors to be tested
	Secure – not easy to forge, clone	Phone: yes Token: no. Requires update	5G security risks have been	Latest versions (IEEE802.15.4z) has introduced	Gen2V2 is encrypted, RFID	Low possibility to forge and clone	Advantage

		of encryption keys via connectivity or hardcoding	identified, requires investigation	chip level encryption, relay attacks not possible	sensitive to relay attacks	biometrics information	
	Fast, low latency	Depends on configuration, needs testing (large amount of people, line of sight issues)	Release 16 and 17: Features listing yes – requires field validation	High data throughput	Average	Average	Depends on connectivity, speed can be improved through fiducial markers
	Low power consumption	BLE power consumption is low	Low power consumption	Very low power consumption for short range	Low power consumption	No – but less relevant	No

2.4.4 Recommended frictionless technologies

Based on our analysis we recommend taking the following technologies into consideration for frictionless ticketing as summarised in Table 7:

Table 7. Technology Options

Accessibility specific options: Biometrics, Wayfinding

Frictionless & Accessibility modes	5G	Ultra Wide Band	Bluetooth	Biometrics	Wayfinding
Pro	One interactive device for all use cases. 'Over the air updates' – client owns hardware. Infrastructure managed by telco operator	Set and forget UWB technically best fit for purpose	Widespread availability/deep penetration	Most frictionless if done well – will suit a particular segment of PWD	Natural extension of growing navigation industry. Low infrastructure requirements (same as phone)
Con	Black holes, battery life	Easy to be lost	Accuracy and concerns about battery life	Privacy concerns	Requires additional device
Validator requirement	5G New Radio (NR) uses new technologies to provide fast and more accurate positioning than 3G/4G (3GPP) for compatible devices, even for crowded indoor spaces.	Ultra Wide Band (UWB) provides precision indoor tracking up to centimetre-level accuracy using Time of Flight (ToF) Time synchronization	Bluetooth 5.1 recently released in 2019 is future of Bluetooth designed for RTLS (real-time location system) using mesh based model	- Face recognition - Voice recognition	SLAM: Fiducial markers: Designed to allow rapid, low-latency detection of 6D position estimation (3D location and 3D orientation) GNSS/SBAS co-ordinates/3D mapping
▼	For 'everyone' with a 5G smart phone	For 'everyone else' who need a token	Support role waking up tokens and phones	For those who can't use a phone nor a token	Make PT ticketing accessible to 3rd party apps

5G Phone based option (for 'everyone with a smart phone')

A phone-based solution seems to have the best prospect to be scaled among the entire population, due to the fact that it does not require a card, token or other physical asset to be managed. 4G BLE solutions can be developed now, but 5G, which uses an entirely different method of positioning, will become more mainstream in a few years. It is expected that 5G will replace 4G universally, although it may take many years before 5G is available to everyone. 5G will be a mid-term solution, as the solution depends on the roll out of release versions 16 and 17. See Appendix 1.2 for a deep dive on this technology.

Ultrawide Band token (for 'everyone that needs it')

This solution can be developed now for PWD as well as general users. Although it may be cost prohibitive to roll out for all users, it can potentially serve as a backup option for everyone. Even though, for this use case, the technology is in its infancy, UWB is proven and available today, hence this could likely be deployed in the short-to-midterm (1 -3 years). See Appendix 1.1 for a deep dive on this technology. Ubisense (Figure 1), for instance, already has prototype products that would be ready for testing.

Figure 5. Ubisense technology solution

Facial/voice recognition (as an option for those who cannot use a token nor a phone)

This solution is favoured by some PWD and operators, as it is 'truly frictionless'. It could be offered as an option without forcing 'everyone else' to use it. Technically this can be deployed now, with the key dependencies being the 'soft' factors such as regulation and public acceptance. It is proven at airports across the world and increasingly at train and metro stations in Asia. Privately, the use of facial recognition as authentication method on mobile phones is increasingly popular. See Appendix 1.3 for more detail on this technology.

SLAM – integration with (wayfinding) apps

This technology is available; however, it is still in its early days when it comes to universal wayfinding applications. The idea is that the wayfinding app would have access to tickets and purchase them automatically on the authority given by the user. Using this technology can be a preparation for MaaS where third-party vendors require access to ticketing functionality. See Appendix 1.4 for a deep dive into this technology.

Bluetooth

For a future upgrade of the current Opal touch on and touch off technology, we have added Bluetooth technology since it can be used to 'wake up' devices (phones and tokens) when they are in proximity to an area, thus conserving energy when not in use.

2.4.5 Will UWB become obsolete when 5G matures?

Indoor location-based services are vertical applications that have increasingly high demand. Applications such as indoor navigation, asset tracking, geofencing, logistics management, and personnel management reflect significant market potential for indoor positioning. As mentioned in our report, UWB and 5G are the most suitable technologies for frictionless ticketing.

5G is also preparing for the Internet of Things (IoT) device growth as a part of the continuous evolution of 5G. Location services have been added to 3GPP Release 16, finalised in mid-2020, to enable indoor positioning by leveraging the ultra-high signal resolution, 5G's high bandwidth, multi-point measurements, and multi-access edge computing (MEC) deployment.

mmWave, which represents high-band 5G that lives between 24 GHz and 100GHZ can also handle high data rates, allowing data transfer speeds to go over 1 Gbit/s. The complete rollout of Release 16 comes with numerous system enhancements such as Mobile Communication Systems for Railways and more. The adaptation of 5G technology towards public transport will also open up new possibilities as more system enhancements come into place with the initialisation of releases 17 and 18.

5G currently also possesses strong potential to be used for indoor positioning. 5G NR provides a few enhanced parameters for positioning accuracy estimation compared to previous mobile generations, particularly with regards to time-and angle-based positioning methods. 5G technology employs mmWave which supports accurate positioning in the vertical and horizontal dimensions, with the narrower beam and wider bandwidth in mmWave frequencies leading to high precision regarding angle and timing. According to Qualcomm, 5G Positioning is meeting the centimetre-level absolute accuracy requirement of down to 0.3m (Qualcomm, 2021).

There is no doubt that 5G will also penetrate the IoT space – which particularly requires low power, low data rate and long-range communication – and telcos already have CatM and NB-IoT chipsets for this utilising their network. Embedded SIM cards will make 5G tokens smaller without the need for changing SIM cards. Mobile stakeholders are now working with producers like Qualcomm to develop the integrated SIM (iSims) which builds the connectivity directly into the chipset, thus reducing the cost of distribution and power consumption. Since the introduction of these iSims, 5G beams will enable accurate positioning, with less power consumption (Thales, 2022).

The question then is, will UWB become obsolete when 5G matures? Our view:
Even though the future of technologies is notoriously hard to predict, in our opinion, UWB will not become obsolete when 5G matures, due to its inherent advantages described below.

Already established and a clear roadmap
UWB is already established and has a clear roadmap. For indoor positioning use cases, UWB has been particularly suitable due to short range, low power, high data rate and accurate indoor positioning. Real-time positioning systems based on UWB technology are currently at a mature stage in industrial applications, e.g., where the tracking and safety of personnel, vehicles and equipment is required. Other fields include warehousing and logistics (libraries, e-commerce industries, etc.). On the roadmap are wireless measurement, intelligent driving (automatic vehicle entry and exit), keyless car entries, as well as augmented reality (AR), and competitive sports.

This roadmap is driven by several advantages which are intrinsic to UWB:

- **Resilience and penetration**
  UWB's pulse signal, which operates at a frequency range from 3.1 to 10.6 GHz, has a channel bandwidth of 500MHz. With the spectral density restricted to -41.3 dBm/MHz by Federal Communications Commission (FCC), the low power density will not interfere with spurious emissions from other electronic devices operating

in the same frequency band (Memsen, 2022). Since UWB pulses have this large bandwidth, UWB permits better immunity to multipath propagation and narrowband interferences and provides good penetration through materials.

- **Accuracy**
  UWB provides very high accuracy, in particular for short range communication (in 10-15m distance). UWB will be capable for peer-to-peer fine ranging, which makes tokenisation applications based on relative distance between two entities more efficient. The accuracy advantages of UWB are: UWB can measure distance and location to an accuracy of 5 to 10 cm, while Wi-Fi, Bluetooth, and other narrowband radio systems can only reach an accuracy of several meters (Connell, 2015).

- **High data rate**
  UWB provides more than 100 Mb/s effective transfer rate compared with Bluetooth (1Mb/s max.) and 802.11b (11Mb/s). Intel, Panasonic, and Motorola are examples of the players in wireless industry who are very interested in developing UWB. They believe we can achieve data rates of as high as 480 Mb/s within ranges of less than 15 meters (Memsen, 2022).

- **Antenna Size**
  Another advantage of UWB technology resides in the size of the antennas, which, is smaller for instance than traditional narrowband RFID. A typical 5G base station may require several antennas including microwave or millimetre wave transceivers, as well as field-programmable gate arrays (FPGAs), faster data converters, high-power/low-noise amplifiers and integrated MIMO antennas (Hardesty, 2020). UWB does not use MIMO antennas.

- **Low power consumption**
  UWB is less prone to interference due to its wider bandwidth of 7 GHz (3.1 - 10.6 GHz) and each channel is 500MHz. UWB technology has an advantage of low power consumption of 10 mW (much less than 802.11b and Bluetooth technologies), which positions UWB technology as one of the lowest power consumptions to date (Memsen, 2022). Note that, due to the large signal bandwidth, FCC also has put in broadcast power restrictions.

- **Low latency**
  Leveraging UWB connectivity, SPARK has demonstrated sub-0.2ms latency for UWB wireless gaming peripherals, and the company is striving for sub-0.1 ms. This will realise real-time positioning with low latency and can instantly sense the movement of the tracked object (Nabki, 2021).

- **Operating model and spectrum license**
  On February 14, 2002, the FCC authorised the unlicensed use of UWB in the frequency range from 3.1 to 10.6 GHz, while 5G will be operated by commercial vendors as the 5G spectrum has been auctioned at a high cost to a limited number of operators. 5G for indoor coverage requires mmWave small cell installations, which will be installed by a Telco. However, UWB infrastructure will need to be installed by owners. Even though the capital expenditure (CAPEX) may be higher, the consequent advantage of UWB is that a deployment is owned by the user, allowing for greater control and customisation, as well as no telco profit margins to be funded.

Based on these unique advantages, we think that UWB can have confidence in their roadmap and will earn its complementary place alongside 5G, to bridge the gap between long range, high data rate transceivers (Wi-Fi and 5G) and short-range low data rate solutions.

2.4.6 What are the differences between RFID and UWB?

In our view, Ultra-Wide Band is the 'perfect RFID'.

- Higher accuracy: UWB can provide more accurate positioning data due to ToF method
- Lower power consumption
- Higher reliability: pulse emissions ensure that UWB does not interfere with other communications or is interfered with
- Higher data rate: This will enable more complex messaging to be transferred in the future
- Lower latency: The very short impulses enable the reduction of the communication latency
- Low power output also makes UWB signals difficult to detect by unintended users. The low duty cycle enables ultra-low power and increases resistance to jamming or interference

For clarity, we have summarized the differences between RFID and UWB based on key technical features in Table 8.

Table 8: Why UWB is the perfect RFID (Source: CTI Analysis, see Appendix 1 and 4 for background)

	Active RFID	**UWB**
Frequency/ interference/ reliable	Low Frequency (LF) 125-135 KHz (used for detection) High Frequency (HF) 13.56 MHz Ultra High Frequency (UHF) 868-930 MHz (data transfer) Microwave 2.45 GHz Microwave 5.8 GHz Easier to be jammed/higher chance of interference due to collisions with other RF signals	3.1 to 10.6 GHz Interference robust: Not easy to jam, low chance of interference
Communications	Modulate continuous-waveform radiofrequency (RF) signals	Pulse position modulation: 2 nano second pulses Because UWB does not use a high-frequency carrier oscillator, UWB transceivers can be turned on very quickly and transmit a far higher data rate than a narrowband radio for a given power level.
Penetration	Good for low frequencies and active RFID No penetration for passive RFID UHF is easily affected (water, human body or metal)	Low attenuation, good penetration in materials
Data rate	Very low for passive tags Low for active tags This limits potential future applications if they require richer data	UWB uses fast 2 ns pulses to reach Mbps data rates. UWB bridges the gap between long range, high data rate transceivers (Wi-Fi and 5G) and short-range low data rate solutions.
Latency	RFID latency varies. It can range between 10 - 100 milliseconds	UWB offers sub-millisecond latency for near-real-time machine control (e.g., in gaming applications).
Power consumption	Active RFID has a history of reducing power consumption	UWB's pulse modulation inherently consumes very low power
Positioning method	Traditionally based on Radio Signal Strength (RSS). RSS is a very simple technique to implement and can be used by any wireless transceiver, which explains why it is so widely used. Other methodologies (e.g., based on triangulation) are developed to make RFID more accurate and reduce the multipath effect, and RFID is also combined with other technologies to increase reliability and accuracy.	Angle of Departure and Arrival, and Time of Flight UWB can measure ToF from a single trip by measuring the time it takes to travel from one device to the other, you can precisely extract the distance between both objects. UWB uses beams to enable the Angle of Arrival and Angle of Departure (as in 5G and Bluetooth) which does not require triangulation
Positioning accuracy	Medium (dm - m) Several techniques and algorithms are being developed to improve on the accuracy	High (cm - dm) Due to more accurate ToF method and Immunity to the multipath effect
Security	Conventional radio positioning approaches use either the phase or the attenuation of a signal as their indicator for distance estimation, but these parameters can be potentially replicated and tampered by an attacker, by simply repeating or relaying a frame with specific physical parameters.	Reducing the time-of-flight of a signal in order to appear closer is not physically possible. As a consequence, the inherent principle of time-of-flight ranging mitigates attacks against proximity-based systems, and can easily unveil attempts to replay or relay attacks as these attacks typically induce delays much higher than the time-of-flight itself

Range	Low Frequency (LF) 125-135 KHz depends on power, can reach km if required. Ultra-High Frequency (UHF) 868-930 MHz: Short range, needs a supporting LF wake up signal in the ticketing use case	Low rate UWB for longer range up 100 meters, ultra-high rate up 10 meters. UWB is a strong candidate to provide the last 100 meters low latency connections in a 5G system.
Maturity	Siemens carried RFID tags for ticketing in 2014, now switched to Bluetooth app-based solutions. Many combinations emerge; low-cost RFID in combination with other technologies (even UWB) to add data rate or accuracy	Mature in indoor positioning and car manufacturing - several car manufacturers have chosen UWB for frictionless car key (over NFC)
Complexity	Principle system design: low complexity, however the performance can be more sensitive to the each of the local circumstances and may require local testing and configuration	Higher, as a product still needs to be developed for this use case. Time estimations are sensitive to clock jitter, and require higher sampling rates and synchronization, which will increase system complexity and cost. However, this is most likely a 'new normal' requirement for many systems
Cost	RFID is low cost as market is mature	Unknown for this use case

The above differences are well documented in academic research, see Appendix 1 and Appendix 4.

2.5 Regulatory considerations

La Trobe's legal team undertook a regulatory review and literature analysis. The review found that the key legal attention areas discussed in the literature concerning frictionless ticketing systems are:

1. Regulatory context
2. Compliance and Enforcement
3. Privacy and Data Protection
4. Discrimination
5. Payments Regulation
6. Competition Policy and Law
7. Platform Regulation
8. Interoperability

None of the issues identified in relation to these topics prevent the in-principle adoption of any particular technical solution in NSW, although every solution requires attention to the relevant legal issues to ensure that the detailed design fits within a fit-for-purpose regulatory environment.

NSW legislation and regulations may need some amendment to ensure technological neutrality in its transport regulation for the future. For example, the concept of 'authority to travel' is linked to the notion of a ticket as a *physical* item, even allowing for later amendments providing for the use of Opal cards and debit or credit cards. This does not easily fit with an authority to travel conferred by the use of biometrics. This may not be a major issue, as the regulations could be amended, or an exemption obtained. On the other hand, amendment of the 2014 and 2017 Regulations to incorporate biometrics for ticketing may involve significant political considerations and an exemption for the ticketing provisions could shift legal liability from the operator to Transport. Depending on the scope of any pilot project, these challenges may need to be navigated.

There is a degree of dissonance creeping into the regulatory environment as it adjusts to new payment modalities. The Act is drafted with the idea of a paper ticket as its core organising concept with adjustments simply grafted on. The 2014 and 2017 regulations are drafted on the assumption there is a conventional paper ticket or an electronic device as the ticket. While an electronic token can more readily be seen to fall within the definition of a 'ticket' under paragraph (c) of clause 69 of the 2017 regulation,[1] the advent of biometric recognition systems challenges those notions as it is difficult to point to a process by which an authority to travel can be conferred. For example, the *Passenger Transport (General) Regulation 2017* read together with the *Passenger Transport Regulation 2014* confers authority to travel on holders of a conventional 'printed ticket', 'smartcard' or 'any other thing issued…to travel on a public passenger vehicle or train' for which the correct fare has been paid.[2] An authority to travel arising by facial recognition is not necessarily a 'smartcard' (because there is no 'card' nor is there a 'device' that is scanned at a 'smartcard reader') nor is there a printed ticket, but there may be 'any other thing issued' by an operator or Transport 'for the purpose of authorising a person to travel on a public passenger vehicle or train used to carry on the service concerned' and that would be a digital record. It has been suggested that perhaps, in the future, the 'smartcard reader' concept can be used for biometric recognition systems. The unique facial pattern is, like a credit card code, a unique code, the facial recognition camera is the 'smart reader', while the software process or the record linking the person and the travel authorisation can be defined as a digital ticket.

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[1] Cl 69 of the *Passenger Transport (General) Regulation 2017 (NSW)* provides a 'ticket means an authority to travel on a public passenger vehicle or train that may take any of the following forms – (a) a printed ticket, (b) a smartcard, (c) any other thing issued by or on behalf of the operator of a public passenger service or rail passenger service or Transport for the purpose of authorising a person to travel on a public passenger vehicle or train used to carry on the service concerned'. See fn 8 below for the narrow definition of 'smartcard'**.**

[2] Passenger Transport Regulation 2014 (NSW) cl 9 and Passenger Transport Regulation 2017 (NSW) cll 69-71.

“Well, I guess, you know, I really got left behind on a train because I couldn’t notify the guy in that little office thing that I was there and so that he could put the ramp down and then I was like stop, stop, stop the train. And the grumpy man came and said you should have notified us before this. So, I guess a (frictionless ticketing) token could notify the grumpy man in the office that I'm actually there and he needs to, you know, stop drinking his coffee and come out!” (Source: Focus Group)

“I went to the human right commission and explained the case where a PWD traveller was forgotten on the train. The person was played like a ping pong ball after she missed a station. It was not fun for me to explain why. Our existing system is only as good as human intervention. The more we take human error out of it, it should be better. They want to use the technology, but they lack the confidence in our technology. The whole essence of discrimination legislation is equivalence. The PWD wants to be independent. I think a solution that allow us to take out those horrible mechanical gates is worth pursuing but it's not just only one solution.” (Source: Operator workshop)

3. Next steps and implications for trials

3.1 Next steps

3.1.1 Suggested programs of work

Delivering frictionless ticketing will require a multi-disciplinary approach, including customer experience mapping; strategy and policy design; technology development; business process mapping; operations planning; legal assurance; and revenue assurance. Table 9 below suggests a program of work that would focus not only on the solution development, but also on the adjacent risks and opportunities. These activities would apply to all four of the technology options.

Table 9. Suggested programmes of work

Reliable MVP and business integration (Priority)	1. Proof of concept: User centric design, product development, testing 2. Quantitative testing: refinement and quantified benefits 3. Deployment testing: impact and results
Added value	What added value services can be delivered at the introduction of frictionless ticketing? E.g., ramp requirement notification, lift operation, hidden disability acknowledgement, location in case of emergency
Frictionless ticketing and fare evasion	Conduct behavioural research/analysis: Will frictionless ticketing reduce or increase fare evasion? Develop fare evasion verification methodology that officers can easily use. Develop mitigation options: CCTV to recognise repeat offenders?
Data	Prepare data analysis capabilities: Leverage frictionless ticketing data and turn into planning improvements. What improvements can likely be delivered first?
3rd party integration	Prepare the capability to extend: - Ticketing functionality to 3rd parties - Ticketing to payment of 3rd party providers (e.g., parking)

3.2 Implications for trials

3.2.1 Implications for technical trials

CTI applies a staged approach to trials: First the technology needs to prove itself in lab or controlled situations so that the research questions with regards to performance can be answered. End user feedback is preferably gathered in controlled situations for reasons of efficiency. Life trials are complex and costly and are hence only recommended when remaining research questions can't be answered otherwise. CTI, together with Transports' research team have worked on the below lab trial objectives, with further trial design to be decided at a later stage once the Lab Trials have been completed.

Table 10. Lab test objectives - technical performance

Criteria Group	Evaluation Factor	Use case	Test Scenario/method
Accuracy	Accuracy	Detection accuracy	Check the success rate and latency - when going in and out of range
	Precision	Position Accuracy	Check the centimetre-level accuracy achieved - in 2D and 3D space - variation with number of anchors used - refresh rate - other factors
	Tracking	Real-time Tracking Accuracy	Check precision and accuracy in live real-time tracking while in the detection zone
	False positives	False detection	Check if system does not generate false positives, or detects the tags out of desired/configured zone
	Coverage: Range	Detection Range	Check the coverage/detection range of the reader/anchor
	Coverage: Configurable range	Adjustable coverage radius or beam	If possible, with the range configuration and anchor alignment, test various detection zones - small, big, wider, narrower, directional, etc
Reliability (resilience)	Detection throughput	Multi-tag detection	To simulate the multi-tag detection throughput in peak hours - use multiple tags in small areas in and out of the detection zone and test the success rate
	Infrastructure effect	Detection in crowded areas	Check success rate by simulating the crowded bus or train station (people, metal, objects, etc) - use multiple tags with congested space with multiple objects - metal, water, glass, wood plastic, etc
	Line of sight	Non-line of sight detection	Test the success rate of detection inside pocket, bag, and congested environments Try to fail the detection and identify the items that causes non-detection
	Wall penetration	Effect of obstructions	UWB can detect the object through walls - test across walls, metal, glass, door, etc
Speed: Responsiveness, Low latency	Latency	Detection speed/latency	How quickly it detects the new tag, as it comes into range - check the logs and detection time with location - can it identify a running person
	Refresh Frequency	Suitable refresh/rate for timely detection	Check the optimal refresh rate for automatic gate opening while BIBO/Walk in/Walk out (WIWO) scenario
Identification and Security	Security		Verify specifications and its application
	Identification	Unique Id - modifiable or not	Admin testing configuration and integrity
	Encryption		Verify specifications and its application

Criteria Group	Evaluation Factor	Use case	Test Scenario/method
Setup - Installation Feasibility, Maintenance, etc	Mandatory installation	Minimum installation infrastructure required	Check what are the minimum installation requirements at a site to make it working - in static as well as moving site like bus
	Installation effort	Ease of installation	How long does it take to install a demo setup – incl. vandalism concerns
	Installation hardware form factor	Reader form factor of key components - anchors - antenna - time sync, etc	Check the portability for various site configurations
	Networking	- any other n/w device, time sync, etc - connectivity and wiring	Check and test the networking requirement and connectivity configuration for a working setup
	Ruggedness/maintenance	Protection against rough environments/weather conditions, humidity	Check if it can sustain tough conditions such as dust, water, hot environments, vibration, etc
Data Protection	Vandalism/theft	Data protection in theft or vandalism of anchors	To evaluate if local data is kept, secured and protected if device is stolen
Integration	SDK API	Support for 3rd party system integration	To evaluate the SDK API interface to control and integrate with client systems
	Events	External event interface	To evaluate the event interface for external systems for integration
	Configuration	Configuration interface	To evaluate the provisioning and configuration interface
	Performance reports	Performance monitoring	To evaluate whether system provides the performance monitoring and reporting interface
Power management	Battery life/powered	Tag Battery consumption	Test the battery consumption in various configurations: - with various refresh rates - active when in range - passive when not in range - various data rate

3.3.2 Implications for live trials: Regulation

What options are at hand to organise a live trial within the current regulatory boundaries?

As mentioned in the regulatory review, current regulations are outdated. The question is what options are available for a trial to be conducted within the limits of the regulation. There are several options, some short term and some longer term that have been discussed with Transport's policy and legal teams.

3.3.3 Implications for live trials: Communication

How to introduce frictionless ticketing trials

Today's concession holders may receive the frictionless ticketing solutions as described in this document as an *increase* in 'friction' – after all, they travel for free at the moment, and only need to bring their concession card. Hence, the introduction of frictionless ticketing will require thoughtful communication. The strongest arguments to introduce frictionless ticketing are not only in the ease of use, but also in the opportunities delivered by the collected data. Examples are provided in the below table.

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Table 11. Worries of PWD and potential solution

PWD worry about ….	Potential solution
Finding the gate and it opening/being opened for them	Automatically opens, even if no-one is there
Making it to a medical appointment	Integrate appointment in planning, notify medical practitioner of progress
Entering the wrong bus or train	Get a warning message when stepping into the wrong bus/train
Emergencies	Be found and get info on preferred channel in case of emergencies
Making it to the right connection in time	Provide accurate wayfinding, hold the connecting mode of transport
Availability of assistance for ramps	Confirm in advance that someone is ready to help

“I think the more inclusive and easier things are that in the public space, which public transport is, that to me is probably the bestselling angle of it, which is the inclusion and trying to make it work for everyone so there is less of that divide between an able-bodied person and someone who's disabled because it's just going to work for everyone.” (Source: Focus Group)

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14. See also appendices

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