Overview of Options to Collect Vehicle Generated Data to inform Traffic Management Systems

Final Research Report - Milestone 1

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EXECUTIVE SUMMARY

Linking data from freight vehicles with traffic management systems stands to provide a number of benefits. These include reducing congestion, improving safety, reducing freight vehicle trip times, informing alternative routing for freight vehicles, and informing transport planning and investment decisions. There are a number of different methods to detect, classify, and track vehicles, each having strengths and weaknesses, summarised in Table 1, each with different levels of accuracy and associated costs. This report provides an overview of such technologies, considering both on-board devices, such as GPS, along with equipment that is required to be embedded in transport infrastructure, such as CCTV and video analytics.

Technology in this space is advancing quickly having started with a focus on infrastructure based sensors and communications devices and shifting quickly to GPS and mobile devices. It is likely that there will be two main categories of data collection, the first involves any use cases that require ultra-low latency of the data, meaning almost immediate transfer of data, such as collision avoidance and other safety applications, and the other involves use cases that can allow a small delay in the receipt of data, such as traffic management. It is likely that safety related data transfer will need to be done using vehicle-to-vehicle systems based on short range to ensure very fast signals are passed from one vehicle to another in the case of a safety concern. However most other forms of vehicle generated data will be able to be transferred adequately via mobile networks, especially with the upgrade to 5G, allowing devices to be portable rather than fixed to vehicles and avoiding the need to install roadside hardware.

Based on a materiality study by the partners, from the range of options presented in this report the following list was seen to be of most importance by Project Partners:

- GPS Trackers: Vehicle Tracking and Identification.
- Weight Sensors: Vehicle Weight.
- Mobile Network Communication: Vehicle Tracking and Identification.
- Video Analytics: Object Detection and Classification.

A key learning from the project is that although detecting the location and classification of freight vehicles stands to provide valuable information for traffic management and transport planning, the potential to improve the overall functioning of the transport network is limited as the system does not know the intended route or destination of the vehicle. Hence, in order to be effective at the network level the systems used must go beyond spot detection of vehicles, often moments before they arrive at an intersection, to include some form of appreciation of the intended route of the vehicle. This then allows intersections along the route to be informed by the likely arrival of the vehicle and efforts to reduce trip times can be coordinated across multiple intersections.

It is envisaged that in the not too distant future all vehicles will provide some form of data to the traffic management system to allow better functioning of the transport network, however, the form of this data will be important and the transition to such a situation will require overcoming three key barriers, namely:

1) *Overcoming a reluctance to share data*: A key barrier to linking either freight vehicle location or routing data with traffic management systems is the willingness to share such data due to concerns about its potential use by unauthorised parties that may affect competitive advantage, or its potential use to enforce regulatory compliance that would otherwise not be enforced.
2) *Lack of understanding of benefits*: Given it is early in the process to link vehicle generated data to traffic management and planning there is currently a low level of appreciation of the tangible benefits to both freight operators and transport network managers.

3) *Increasing the capacity of Traffic Management Systems*: As such data has not been available in Australia, current traffic management systems are not yet appropriately equipped to process the data and provide network-wide benefits in real time. Increasing such capacity needs to be undertaken in stages following the identification of key data required to enhance traffic management.

It is recommended that a strategy be considered to transition over time to disclosure by freight vehicles of data such as vehicle classification, location, and intended route. This will require providing an appropriate assurance that data will be used only as intended, demonstrating the value to both freight operators and transport network managers, and progressively increasing the capacity to use such data in transport network management and planning to deliver mutual benefits increases over time.

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PART 1: INTRODUCTION

The purpose of this report is to present an overview of options to collect and harness data on freight vehicles (collected from either GPS trackers, RFID tags, Wi-Fi signals, fixed cameras, or satellites) in order to support traffic management systems to improve conditions for all road users while delivering direct value to freight operators. According to the Australian Bureau of Statistics (ABS) the level of freight carried on public roads is set to increase, as shown in Figure 1, and as such it is important that freight vehicles are effectively managed as this can deliver benefits for transport agencies, private sector logistics companies, and the road using public. Better freight management reduces congestions, leading to less pollution and a range of direct and indirect economic benefits. The Australian Logistics Council has recommended that the ABS establish a transport account to its national accounts that separately reports the value of freight transport for the economy as a whole. [1]

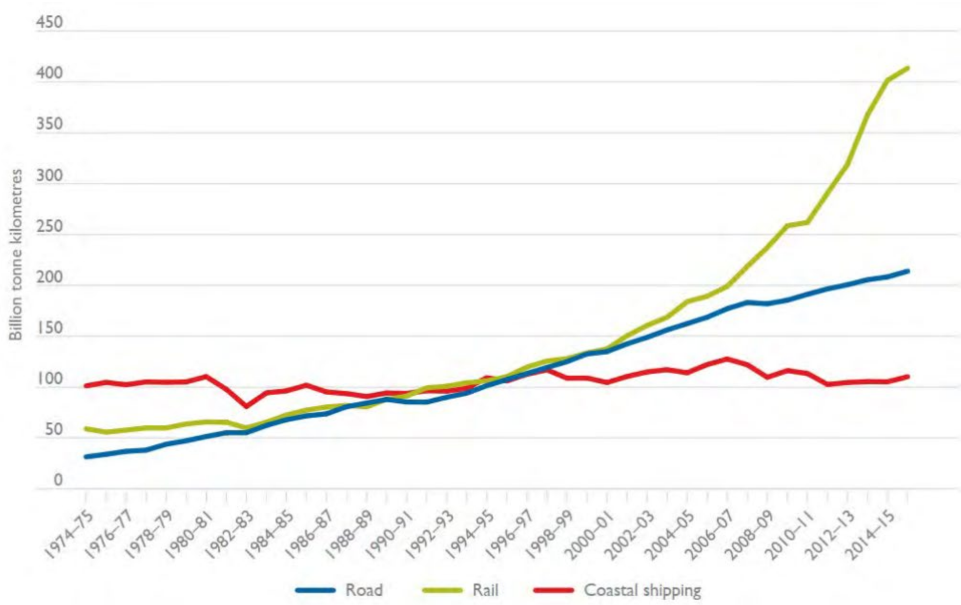

Figure 1: Changes to the level of Freight in Australia for each main mode
Source: ABS (2017) [2]

The freight sector now has more opportunities than ever before to harness technology to increase productivity and streamline transactions (such as Blockchain Technology) along with improve routing, and collaborating with traffic agencies to enhance traffic management for mutual benefit (using Artificial Intelligence and associated data collection technologies). This report focuses on the later and begins with an overview of technologies that can be used to detect, classify, identify, and track freight vehicles. This includes both on-board technologies (such as GPS trackers and digital licence plates and Radio Frequency Identification technology) and infrastructure-based technologies (including aerial imagery, Wi-Fi, and video analytics), as summarised in Table 1. Following this, the report considers how such technologies can interact with traffic management, and the associated implications. This new area of research and practice that seeks to balance the needs of traffic management systems (such as data on location and intended routing of freight vehicles) in order to better manage traffic and prevent bottlenecks and congestion while delivering tangible benefits to freight companies stands to be of great interest in the coming decade.

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[1] ALC (2018) ALC Brief - Inquiry into National Freight and Supply Chain Priorities, Australian Logistics Council.
[2] BITRE (2017) Yearbook 2017: Australian Infrastructure Statistics, Statistical Report, Bureau of Infrastructure, Transport and Regional Economics Canberra, ACT

Given the need for data standardisation and increased interoperability are now well understood,[3] a key consideration for selecting the appropriate option, along with suitability to stakeholders, is minimising costs to transport agencies associated with appropriately accessing and utilising real-time freight data. At first glance, this seems to be best done by direct access to freight operators' data with many freight vehicles equipped with GPS technologies, however in practice this raises a number of questions such as how the data will be used and if it's worth releasing. If such an active method cannot be achieved then there are a range of passive options each with benefits and short-comings as outlined in Table 1, such as either additional on-board technologies (see Part 3.1) or technologies embedded in the transport infrastructure (see Part 3.2).

There are existing technologies embedded into transport infrastructure that are used to manage intersection signalling, such as the 'Sydney Coordinated Adaptive Traffic System', or SCATS, that is used at some 55,000 intersections in 28 countries. The system boasts improvements such as a 28 percent reduction in travel time, 25 percent reduction in congestion, 12 percent reduction in commuter costs, and 15 percent reduction in vehicle emissions. The effectiveness of the system is based on the vehicle detection options which are typically a hard sensor embedded in the roadway at a set interval from the intersection, often set at around 30 metres to detect queues. Such systems provide the potential for greater functionality at the traffic network level if it can be provided real time vehicle movement data.

[3] See: Hargroves, K., Stantic, B., and Conley. D (2016) Big Data, Technology and Transport: A Sustainable Built Environment National Research Centre (SBEnrc) Industry Report, Curtin University and Griffith University, Australia.

PART 2: OVERVIEW OF FREIGHT VEHICLE DATA COLLECTION OPTIONS

In terms of freight management applications, the key feature is the capability to track in real time the position of the vehicle. This can be done using a range of technologies that either are located on the vehicle such as GPS trackers and RFID Tags or are part of the network infrastructure such as CCTV cameras, satellites, mobile phone towers, Wi-Fi receivers and RFID readers. This section provides a summary of these technologies in order to inform selection of preferred technologies for implementation as part of a system to link to traffic management systems.

Table 1: Summary of Strengths and Weaknesses of Options for Vehicle Detection, Classification, Identification and Tracking

	Strengths	Weaknesses
On-board Technology Options		
GPS Trackers and Telematics *(vehicle tracking and identification)*	• Provides detection, classification, identification and tracking. • Location data accurate under clear sky conditions to a 5-metre radius. • Can be linked to vehicle information. • Roadside equipment not required.	• Requires a device to be installed on the vehicle. • If a private device is installed there may be a reluctance for data to be made available to transport agencies.
GPS Digital Licence Plates *(vehicle tracking and identification)*	• Provides detection, classification, identification and tracking. • Provides location data using GPS that can be linked to vehicle information. • Allows changeable display. • Roadside equipment not required.	• Requires a high cost device to be installed on the vehicle. • Requires management by licencing authority. • GPS may cease working if number plate is hit or damaged.
RFID System *(vehicle tracking and identification)*	• Provides detection, classification, identification and limited tracking. • Provides location data that places vehicles in the read range. • Can be linked to vehicle information. • Can be integrated with objects tracking system.	• Requires a device to be installed on the vehicle. • Requires receivers to be installed roadside (avoiding metal surfaces). • Tracking can only be done with adequate roadside receivers.
Weight Sensors *(vehicle weight)*	• Provides real time load information rather than requiring a weigh-bridge. • Can allow prioritization based on actual weight rather than vehicle type and length.	• Requires a device to be installed on the vehicle and trailers. • Requirement for a communication system to export data. • Requires calibration and maintenance to ensure accuracy.
Dedicated Short Range Communications *(vehicle detection)*	• High Speed reliable data transmission. • Standardised frequency across the equipment, meaning standard equipment across heavy vehicles, reducing costs.	• Requires a device to be installed on the vehicle. • Technology a low level of maturity. • Short range capabilities only.
Mobile Network Communications	• A multi-use device allowing a range of functionality, easily updated.	• Requires a mobile device to be carried in the vehicle.

(vehicle tracking and identification)	• Allows two-way communication. • Readily available, low-cost, non-specialised technology.	• Signals from other mobile devices may interfere with data transmission.
Infrastructure based Technology Options		
Aerial Imagery *(Object detection and vehicle classification)*	• Provides detection and classification. • Provides 80% accuracy for object classification. • System can deliver a range of functions along with vehicle identification.	• Requires senders and receivers to be installed roadside.
Wi-Fi System *(Object detection and vehicle classification)*	• Provides detection and classification. • Provides 82% accuracy for object classification.	• Uses satellites and may have up to 10 minute latency. • Early stage technology.
Infrared Traffic Logger *(Object detection and vehicle classification)*	• Mature technology in use worldwide with >98% accuracy for speed detection and vehicle classification. • Non-invasive, versatile deployment, minimal power and servicing requirements. • 25+ year operating life and resistant to extreme weather conditions.	• Requires on-site installation of physical unit at each monitoring point. • Dated software compatibility. • Limited networking capability.
Bluetooth System *(Object detection and vehicle speed)*	• Well established technology with decent travel time detection. • Avoids requiring permission for detection.	• Requires receivers to be installed roadside, typically in traffic signal control boxes. • Only detects 10-15% of vehicles.
Video Analytics - Object *(Object detection and vehicle classification)*	• Provides detection and classification. • Can use existing cameras with 96% accuracy for vehicle and other roadside object classification. • System can deliver a range of functions along with vehicle identification.	• May require additional multiuse roadside cameras to be installed.
Video Analytics - Plate *(Vehicle identification using number plate recognition)*	• Provides detection, classification, identification and tracking. • Can use existing cameras with 98% accuracy for vehicle identification. • Can be linked to vehicle information.	• May require additional multiuse roadside cameras to be installed. • Privacy considerations for licencing authority.

The collection and handling of information is a key concern for vehicle detection and tracking, particularly if it can be used to identify an individual. Solutions using GPS or RFID for instance rely on linking on-board devices with existing databases to classify vehicles by matching unique identifiers, i.e. serial numbers or license plate numbers, to specific vehicles which could potentially be used to identify the owner or driver. According to Surveillance Devices Act 1998 however such a device can only be attached to a vehicle with the "*express or implied consent of the person in possession or having control of the vehicle*" unless by a law enforcement officer. Given that permission is needed to attach a tracker or device to the vehicle it may be easier to attain if the device is activated only when the vehicle is on a particular class of road so that details about after-hours use are not accessed.

According to the Australian Privacy Principles Guidelines, if entities do not have access to sensitive information, such as registrant of the car, then license plate numbers may not be considered as personal information as with this information alone, the entities will not be able to identify the individuals in this case. This may be able to be achieved by the use of a permissioned Blockchain where only partial information is accessible with a licence plate number, such as the make, weight and classification of the vehicle. In a case where individuals can be identified there are a range of methods to de-identify the data for use in tracking to support traffic management outcomes. Other methods such as video analytics-based vehicle detection and classification, Wi-Fi signal-based detection, and aerial imaging detection rely on training data on typical vehicle dimensions and configurations in order to identify vehicles and as such do not need to collect private information.

2.1 Onboard Technology Options

The value of on-board options is that the technology can be embedded into vehicles and be made to be tamperproof, or illegal to tamper, and do not rely on the driver or occupant of the vehicle to participate in the tracking process.

2.1.1 GPS Trackers: Vehicle Tracking and Identification

GPS Trackers are now widely available and are becoming a standard feature of newer trucks and freight vehicles. In order for a GPS tracker to identify its own location it needs to connect via radio waves to a number of satellites. Once its location is established it then communicates this to a mobile phone tower every 3 minutes if the tracker is moving and every 30 minutes if it is stationary. The data is then sent to a server to be accessed by fleet managers etc as shown in Figure 2. This can be used in a number of ways including identifying if a vehicle has moved into or out of a specified area, called geo-fencing, triggering a message to be sent to the owner say in the case of theft or unauthorised use and even allowing for the engine to be shut off and siren set off.

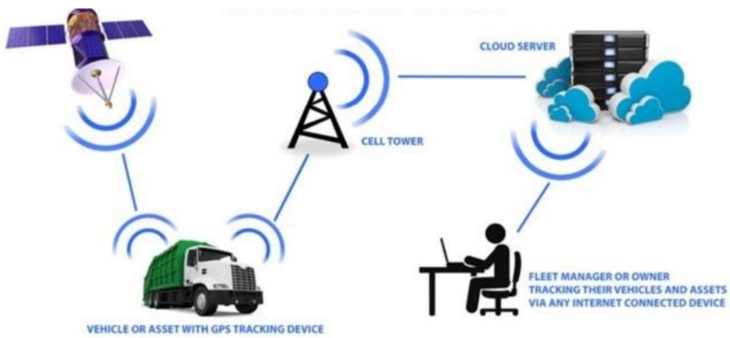


Figure 2: A typical freight vehicle GPS tracking system and associated technologies

When considering the deployment of a GPS-based device for vehicle tracking it is important that the device has a real-time communication link to the application servers. The device should not only send its location information but other information can also be included such as the type of vehicle, data on driver behaviour, levels of fluids, temperature of the engine, etc… with this increased data transfer referred to as 'Telematics'. Such technology has been successfully applied to emergency vehicles to assist with reducing trip times by allowing the vehicles to communicate directly with traffic light controllers to gain signalling priority.[4]

Despite the advantages, there are some issues with the use of a real-time GPS-based tracking system that require consideration prior to deployment.

[4] Eltayeb, A., Almubarak, H., and Attia, T. *eds* (2013) A GPS based traffic light pre-emption control system for emergency vehicles. 2013 International Conference on Computing, Electrical and Electronic Engineering (ICCEEE); 2013 26-28 Aug. 2013.

1. As the system requires transmission of data almost instantly to be accurate, network coverage needs to be adequate for the duration of the journey. However, that being said, GPS coordinates can be kept in memory until reception is available.
2. Adequate power supply needs to be maintained suggesting that the device needs to be connected to the vehicle power supply rather than using an inbuilt power source like a battery that may fail.
3. GPS-based systems require the devices to have clear line of sight to satellites, hence vehicles travelling on underground routes would not be detected and would require other means.

2.1.2 GPS-enabled Digital Licence Plates: Vehicle Tracking and Identification

Technologies such as GPS trackers and RFID tags can be embedded into technology that can be physically mounted on vehicles, such as a digital licence plate. This can be particularly useful if the freight vehicle does not have such technology on board or if a newer truck wants to separate data flows with two sets of equipment. Digitising licence plates can involve a device being attached to existing licence plates by government authorities or the plate itself can be replaced by a digital display controlled by the registration agency. For instance, in the US the company Reviver Auto has created the 'RPlate' which is a fully digital licence plate that not only tracks the vehicle but allows the number and design of the plate to be changed. The RPlate has been approved for use in several US states (California, Arizona, and Michigan) and legislation has been passed or is currently in development to allow trials in several other states. In 2018 the RPlate was deployed in Sacramento and trialled in Dubai. There has also been discussion in the UK about whether to introduce this technology, although we are not aware of any current or past trials.

The RPlate is battery powered and includes a high definition digital screen and allow users to connect to their vehicle at any time through a smart phone app as shown in Figure 3(a). The key features include the ability for automated registration, parking, and toll payments and customisation of the screen text and logos. The RPlate Pro includes a GPS system that allows vehicle tracking and can display the car's location if it is stolen as shown in Figure 3(b).

(a)

(b)

Figure 3: a) RPlate showing digital display and link to smart phone, b) An example of an RPlate on a vehicle that has been registered as stolen

One of the major barriers is the cost – the Pro version costs $499 US plus a monthly service charge. Features like the high-definition display and message customisation are not relevant for freight companies, but a base model could be developed that is substantially cheaper. Another key concern that has been expressed by different community bodies is the privacy concerns if smart plates were deployed widely and governments had access to individual driving behaviour, routes, locations, etc. In addition to Reviver Auto, a number of other companies are developing digital plate products, including LicenSys, International Proof Systems, and Compliance Innovations. LicenSys has developed a smart plate called the 'RAIN Plate' that includes an RFID chip and an antenna rather than a GPS tracker. The plate is designed to interact with overhead, in-road, or handheld sensors to identify and locate vehicles. Unlike GPS, which can provide second-by-second tracking, the RAIN Plate will only identify vehicles when they are in the proximity of the RFID readers. LicenSys are promoting the RAIN Plate as a solution to provide toll monitoring, geo-fencing and access control, and minimise vehicle theft, however the product does not seem to be commercially available as yet. However, it would likely be cheaper than the RPlate and it could be a more appropriate solution for freight companies; the RPlate has a digital display and is geared towards the consumer market, whereas no such display is provided on the RAIN Plate and there is no ability to customise the plate messaging.

Compliance Innovations is also developing a digital license plate. Their plate is battery-powered and only a small portion of the display is digital and can be altered, unlike the RPlate where the entire plate is digital. The plate connects through a mobile phone network to provide tracking of vehicles and it is marketed as a way for government agencies to easily keep track of uninsured, stolen, or unregistered vehicles. The display can be changed remotely so that law enforcement agencies can more easily identify violating vehicles. There has been no update on Compliance Innovation's website since 2017 so this product is in a much earlier stage of development than the RPlate.

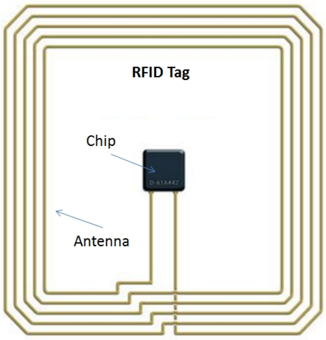
Smart plate technology is still in its infancy and a Google scholar search did not reveal any academic studies exploring the use of this technology to streamline traffic management. A number of media articles discuss the deployment of the RPlate, but they do not provide any hard facts and figures about the benefits. There is no media coverage of any of the other solutions. Out of the different smart plate choices identified above, the RPlate and RAIN Plate seem to be the most viable. The other solutions proposed by International Proof Systems and Compliance Innovations seem to be a long way off being commercially available and the websites for these companies are out of date, indicating that these projects may be paused or even cancelled.

The key difference between the RPlate and the RAIN Plate is that the RPlate can provide second-by-second GPS tracking through a mobile phone network, whereas the RAIN Plate relies on RFID readers that would need to be installed at key locations in the road network. The readings from the RAIN Plate would be discrete snapshots of location at the sites where RFID readers are present, rather than a continuous trajectory provided by GPS tracking. The additional cost of installing RFID readers in the road network would need to be weighed up against the cost of the RPlate, which is the more expensive option. If neither of these options is suitable, then a custom solution may need to be investigated. However, this would likely involve considerable research and development to ensure that the solution is robust, can handle high speeds, adverse weather, and other factors, and hence an existing solution is preferable. Other alternative detection method such as surveillance cameras and RFID-based solutions may be considered if vehicle detection in these areas is crucial in managing traffic.

2.1.3 Radio Frequency Identification (RFID): Vehicle Tracking and Identification

Another method to track vehicles, and any number of other items, is Radio Frequency Identification (RFID) technology, which has been gaining popularity with increasing deployment around the world as part of what is becoming known as 'Automated Identification and Data Capture' (AIDC) technology. RFID technologies are used in door openers and motorway toll gantries.

In short, an RFID is composed of a digital chip that records data and an antenna (or transponder), as shown in Figure 4(a). The antenna can be used for two purposes. Firstly, in the case of an active tag, meaning a tag that has its own electricity supply, the antenna is used to transmit data via radio waves either continuously or when it receives a signal to do so. Secondly in the case of a passive tag, shown in Figure 4(b), meaning one that does not have its own electricity supply, when the antenna is placed near a RFID reader it receives radio waves from the reader via inductive coupling that are collected by the antenna for use as a source of energy to then send data from the chip back through the antenna to the reader, which is quite ingenious.



(a)

(b)

Figure 4: a) A diagrammatic representation of an RFID tag, b) a roll of commercial RFID tags

RFID technology is widely deployed in the supply chain sector to help with traceability of items as they move along the supply chain, often replacing the previous method that required line of sight to a bar code for manual reading. RFID have also been deployed in the transport sector to identify vehicles. Along with use on Tollways, the first nationwide deployment of RFID technology in transport was carried out by the Ministry of Transport of Singapore in 1998. Singapore introduced an electronic road use pricing system which has since been used to manage traffic congestion through strategic placement of RFID-based gantries that charge road users fees when entering a specific zone. Road users are expected to pay additional fees during certain hours of the day, thus discouraging entry into selected zones to ease congestion levels. Each car carries a passive RFID tag that transmits to the reader a unique ID number; however, the tags have the potential to send more data and this could include ownership details, vehicle class, plate number, VIN Number, etc.

The frequency of the radio waves has a direct impact on the range and transmission rate of the tag as can be seen in Table 2.

Table 2: Comparison of frequency, mode and read range of RFID technologies

RFID Categories	Type of Setup	Frequency	Read Range
Low Frequency (LF)	Passive	125 & 134 kHz	< 50cm
High Frequency (HF)	Passive	13.56 MHz	~ 1m
Ultra-High Frequency (UHF)	Active, Passive	433 MHz (Active), 860 – 960 MHz (Passive)	~ 100m (Active) ~ 10m (Passive)

SkyRFID, a Canadian company, provides a passive solution which can read up to 16 meters and an active solution that can read up to 3 kilometres. Another RFID technology company, RAIN RFID, reports a read rate of 1000 tags per second.

Considerations for the use of RFID tags include:

- Readers and tags must be of the same category for them to be compatible.
- Higher frequency technology allows transmission of data at a higher rate, both volume and speed, over a longer range, but the reading capability is reduced in moist environments.
- Metallic surfaces can reflect the radio frequency waves decreasing the antenna performance, although many RFID technology suppliers have a version of the tag to minimise the impact of metal surfaces.

- When setting up RFID outdoors, ruggedized RFID devices will be required to ensure that the setup can withstand harsh conditions such as dust particles, full immersion in water and a range of operating temperatures.

When considering application of RFID technology to transport the challenge becomes being able to reliably read tags on moving objects, i.e. cars and other vehicles as shown in Figure 5 meaning that active options are likely to be more reliable. When attempting to identify characteristics of the movement of the vehicle such as speed and direction multiple readers are needed. This also requires computation to make sense of the direction of moving vehicles by comparing read logs and respective time stamps i.e. cars moving downwards should first be picked up by 'Reader A' before being read by 'Reader B'.[5]

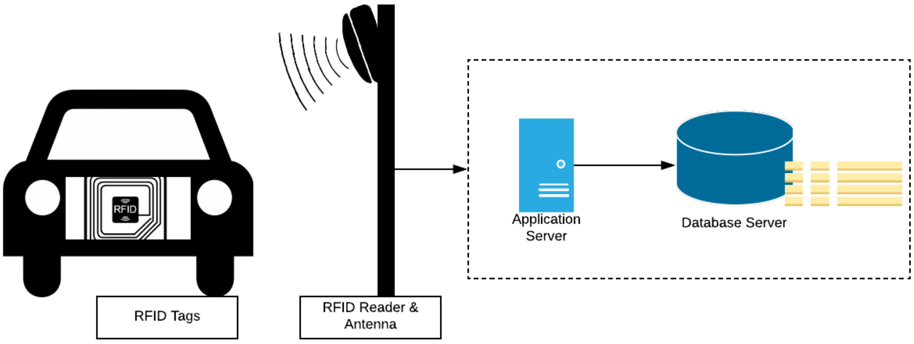
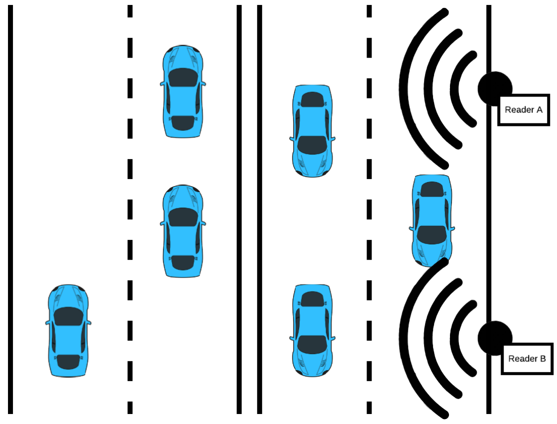


Figure 5: A diagrammatic representation of a transport application of RFID technology

Another important consideration in transport systems is the configuration of the RFID readers. In order to monitor speed and direction a set of two readers is needed as shown in Figure 6(a). For instance, Figure 6(b) shows the RFID gantry system used in Singapore that does not require a long-read range. When considering intersections RFID readers can be positioned to read vehicle tags using higher radio frequencies to allow for longer read ranges.



(a)

(b)

Figure 6: a) A diagrammatic representation of a roadway installation of RFID technology for direction and speed detection, b) An example of such a system in Singapore

Given RFID technology requires both dedicated tags and receivers it can be a higher cost tracking option than the use of GPS technology given the ubiquitous establishment of such technology, however it can provide more accurate results. Table 3 provides an estimate of the cost for typical components that are used in roadway applications, excluding labour, cables, gantries, enclosures and software-related development and supporting infrastructure cost.

[5] Oikawa, Y. (2009) Tag movement direction estimation methods in an RFID gate system. Current Trends and Challenges in RFID. p. 41-5.

Table 3: Indicative costings for core components of RFID technology for roadway applications

RFID Component	Estimated Cost
RFID Readers (Varies according to number of ports as well i.e. 2, 4, 8, 16 ports)	$1,400 to $2,800
RFID Antennas	$190 - 600
RFID Tags (Tags suitable for vehicles)	$15-60

2.1.4 Weight Sensors: Vehicle Weight

Heavy vehicles, from Heavy Rigid through to Heavy Combination and Multi combination trucks, all have a vast weight ranges, depending on loaded or unloaded, or their payload type, given this, using the trucks length of number of axles is not always an accurate depiction of the weight of the truck. The solution of having weight sensors on each axle, both gives the driver and loading party greater potential for safe loading with an even distribution of the weight, and the data of the total combined weight of the truck, trailer and load to communicate with the lights of traffic network. For example, a B- Double with 9 axles, weights 20 tonnes dry, while weighting up to 68 tonnes at maximum payload[6], if traffic lights were to react purely to the number of axles, there would be a conflict of performance between a 20-tonne empty truck, versus a 68-ton loaded 18 axle B Double.

These weight sensors are not a road worth requirement currently for the NHVR, however for drivers and business to ensure their vehicles are roadworthy during operation without the need for a weighbridge, on-board weight sensors are used. These systems are used to ensure even load dispersion and avoid overloading, weight sensors are connected and calibrated through the airbag suspension on the trailers[7] and the rear axles under the 5th wheel on the truck. These systems normally display constantly either on the trailers near the hitch, or inside the cab where the driver can monitor them during loading. This data is also sometimes communicated to the trucks Homebase for quality and monitoring through the In-Vehicle Monitoring System, along with vehicle speed, run time and driver behaviour. The ability for a truck to accelerate and decelerate is greatly impacted by its weight, having and being able to communicate this information to the incoming traffic light, or to the traffic system as a whole, would greatly reduce the effort, time and fuel needed to move through built up areas. For example, a comparison of weights, a 40 tonne Semi Trailer accelerates form 0 to 60km/h in 55 seconds[8], whereas a 68 tonne B-double, takes 71 seconds to accelerate from 0 to 60km/h, if weight sensors, and say numberplate recognition was used as an alternate, without the classification of whether a prime mover is towing two trailers or one, this acceleration difference wouldn't be taken into account.

To use an onboard weight measurement system, and have that information communicated to upcoming traffic lights or to the traffic system as a whole to provide fully loaded HC and MC vehicles with priority for green lights, reducing deceleration and acceleration times of traffics, not just the trucks. This system would require not only on-board infrastructure, but a short-range communication system between vehicle and intersection such as on-board Wi-Fi.

2.1.5 Onboard Wi-Fi (Dedicated Short Range Communication): Vehicle Detection

Dedicated Short Range Communication (DSRC) is a wireless technology that allows vehicles to communicate between other vehicles or infrastructure over short to medium distances. Operating most

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[6] NHVR (2016) *National Heavy Vehicle Mass and Dimensions July 2016*. National Heavy Vehicle Regulator Queensland
[7] TruckWeight (2017) *Air Suspension Sensor – Weight*. TruckWeight.
[8] Di Christoforo, R. (2018) *Field trials to evaluate the acceleration and deceleration performance of heavy combination vehicles*. Advantia.

commonly over the 5.9 GHz band of radio frequency in Australia,[9] vehicles are fitted with on-board units and infrastructure with roadside units such that vehicles can receive communication on road and traffic conditions, and from nearby vehicles. DSRC is a fast and highly secure technology with data only relayed when the units are within range of each other. These units enable Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I) and Vehicle-to-Everything (V2X) communications, allowing all road users and traffic systems to be better managed[10].

Cohda Wireless has been involved in numerous vehicle detection projects such as the Cohda Vehicle-to-Everything Locate trial in New York City. This trial compared the performance of Cohda Wireless roadside and onboard units against a high-quality Global Navigation Satellite System (GNSS). GNSS often experience 'blackspots' in urban areas due to obstructions created by large buildings, leading to inaccuracy. This was shown in the trial where GNSS displayed an inaccuracy of up to tens of metres in location detection whereas the V2X Locate system located the vehicle accurately within less than a metre. V2X Locate system's use of DSRC technology eliminates this 'blackspot' issue by communicating with units that are closer in range and free from large buildings or other obstructions, proving to be a more reliable technology[11].

2.1.6 Mobile Network Communication: Vehicle Tracking and Identification

A promising option for on-board technology is mobile network communication, where a device, such as a smartphone or tablet, is used to collect and transmit vehicle data, such as the Talon In-Vehicle Driver Tablet used by MT Data. Along with typical data such as location, route, and speed, the devise can undertake fatigue management, navigation, incident reporting, messaging, etc. Fuel entry & much more being transmitted back to a central server via the mobile network. The 5G mobile network stands to provide high speed data transmission with low latency allowing real time data to be received and sent by both logistics operators and traffic management systems. The ability to receive real time data on truck locations and provide routing instructions based on current traffic conditions and the ability to provide preferential passage presents a valuable opportunity for both freight carriers and traffic system managers.[12] The use of mobile devices also allows for controls as to the use of data such as being muted or turned off when the device is not on route. Further the use of a mobile device also allows the installation of software that can provide a range of services that can be linked to the logistics company and other service providers, such as Tolls, container park entry, etc.

The cost of equipping drivers with mobile devices may be cost prohibitive for smaller companies, compared to larger operators who may reap short term benefits; however the purchase of such devices could be quickly recuperated due to the multi-use capabilities for connecting to drivers and vehicles. The ongoing cost of maintaining and upgrading mobile devices such as tablets or mobiles is low, they are easily obtained, with no to low hold up due to manufacturing. As devices can be swapped between vehicles as required, the most updated technologies can be utilised without more costly vehicle replacement. The benefits of using mobile networks to transmit data (compared other options such as wireless or Bluetooth) is that the reliability and speed is increasing with all major mobile service providers shifting to from 4G to 5G, and is likely to continue to increase through competition to provide faster services. Further it will be easier to differentiate between in-vehicle devices compare dot say WiFi

[9] 5GAA (2018) White Paper on ITS spectrum utilization in the Asia Pacific Region, 5GAA Automotive Association, July 2018.
[10] Thomas, L., Panicker, S., Daniel, J., and Tony, T. (2016) DSRC based collision warning for vehicles at intersections, 2016 3rd International Conference on Advanced Computing and Communication Systems (ICACCS), Coimbatore, 2016, pp. 1 – 5.
[11] ATIC (2018) "Case Study: Cohda Wireless", Australian Trade and Investment Commission, 2018.
[12] Boban, M., Kousaridas, A., Manolakis, K., Eichinger, J., and Xu, W. (2018) "Connected roads of the future: Use cases, requirements, and design considerations for vehicle-to-everything communications," IEEE Veh. Technol. Mag., vol. 13, no. 3, pp. 110–123, Sep.2018.

or Bluetooth that can pick up mobile devices used by private drivers, walkers, cyclists, and those using shared modes.[13]

In short, the use of mobile devices rather than on-board proprietary devices stands to provide significant benefits and functionality with the potential to increase the efficiency of freight movement, considering the variety of data that may be exchanged across such networks, and the manner of two-way communication. The effectiveness of the system is directly proportional to the level of data sharing parties agree to, the capabilities of data analytics centres and capacity of the network infrastructure.

2.2 Infrastructure based Technology Options

2.2.1 Aerial Imagery: Object Detection

Satellite images combined with artificial intelligence is another method of detection and classification of vehicles. The approach segments different objects, such as vehicles, for classification with up to 80 percent accuracy. However, unlike roadside cameras, satellite imagery cannot always provide real-time data that can be used to detect vehicles and the current traffic conditions, with it being more like near real-time. The Australian Bureau of Meteorology uses imagery from weather satellites with latency of 10 minutes, which would not be sufficient for traffic management. Another challenge would be identifying vehicles under any objects obstructing the line of sight. This could be common objects that are found such as overpasses, gantries and trees. Vehicles in tunnels are, needless to say, out of sight and will not be able to be detected. This method may be a viable option in the future when the technology can provide real-time data and avoiding roadside infrastructure.

2.2.2 Infra-Red Traffic Logger: Vehicle Detection

The Infra-Red Traffic Logger (TIRTL) is a non-invasive, light-based traffic monitoring system that can count, classify, and measure the speed of vehicles passing a specified point. Developed in New South Wales in 1997, it was released commercially in 2002 and is now used in 16 countries. With many applications from overhigh vehicle detection, toll systems, traffic monitoring, speed and incident detection systems, the capabilities of an infrared system are large, and many are already in operation in urban environments. there is a speed camera and a point to point camera system for heavy vehicles.

The TIRTL system can detect trucks, by the number of axles or length, or height as they approach an intersection, and depending on their speed, dictate the outcome of the lights ahead. This would require a system to be installed prior to every intersection that experiences large numbers of heavy vehicle traffic, however it would be consistently accurate. This system would operate similar to the Wi-Fi signals system below, however the TIRTL system is superior in its reliability in extreme weather events. These IR transmitters and systems have a reasonable product life of up to and beyond 25 years, their implementation does not damage the road surface, and the servicing of the equipment takes 10 minutes per logger.

The system calculates the time delay between interruptions in infrared light signals and uses this information to make assumptions about traffic flow. Depending on its positioning, the system can make assumptions around vehicle count, length and height, it is also capable of differentiating between an unlimited number of lanes and classifying vehicles with an accuracy of 98.4 percent with 4 lanes of 100km/h traffic. TIRTL also has and accuracy of greater than 98 percent for speed detection at 200km/h. The TIRTL system is well-established and low-cost, with broad ranging traffic management applications and offers ultra-low power consumption (constant 6 – 24V solar operation). However, TIRTL is limited by the number and location of installed units, benefitting most from wide-ranging implementation.

[13] Masini, B., Bazzi, A., and Zanella, A. (2018) "A survey on the roadmap to mandate on board connectivity and enable V2V-based vehicular sensor networks," Sensors, vol. 18, no. 7, p. 2207.

Furthermore, although the on-board computing is versatile, the dated software may create compatibility obstacles with more cutting-edge systems and limits its overall networking capability.

2.2.3 Wi-Fi Signals: Vehicle Detection

It is possible to use Wi-Fi signals to detect and potentially classify vehicles by setting up Wi-Fi transmitters and receivers on each side of the road to detect and record a passing vehicle, as shown in Figure 7.[14]

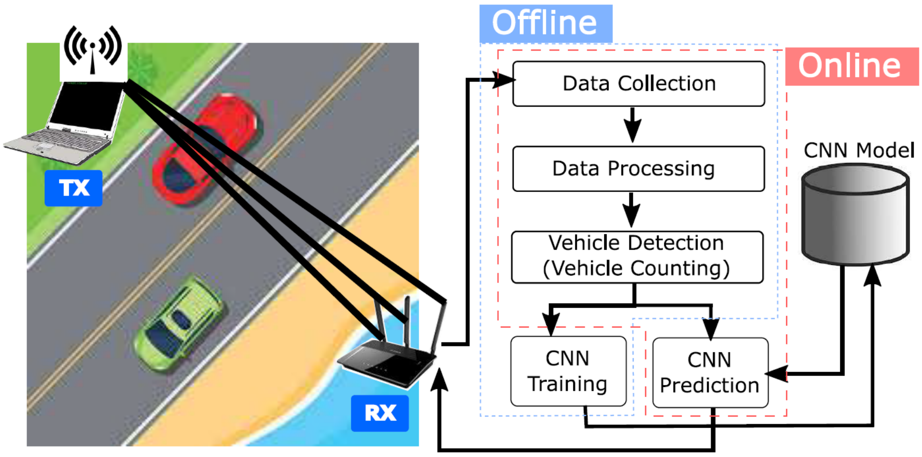

Figure 8: An example of a Wi-Fi based vehicle detection system - DeepWiTraffic

The system uses a convolutional neural network to study the incoming data from the Wi-Fi receiver and can recognise five main classes of vehicles: bike, passenger cars, SUV, pickup trucks, and large trucks with an accuracy of 82.4 percent for both lanes combined, compared to 96 percent for optical recognition using roadside cameras. This method is deemed in an early development stage as there are limited studies on its use to classify vehicles and no readily available solutions in the market. It is likely that further investigation is required to see if the technology can be scaled up for use on dual carriageways.

2.2.4 Bluetooth Signals: Vehicle Detection and Speed

It is possible to detect Bluetooth signals in vehicles using roadside equipment for use in detecting speed. The roadside detectors, as shown in Figure 8, are typically spaced at 50 metre intervals and detect the Vehicle MAC address at multiple locations to estimate vehicle speed.

[14] Won, M., Sahu, S., and Park, K. (2019) Low Cost WiFi-Based Traffic Monitoring System Using Deep Learning. DeepWiTraffic.

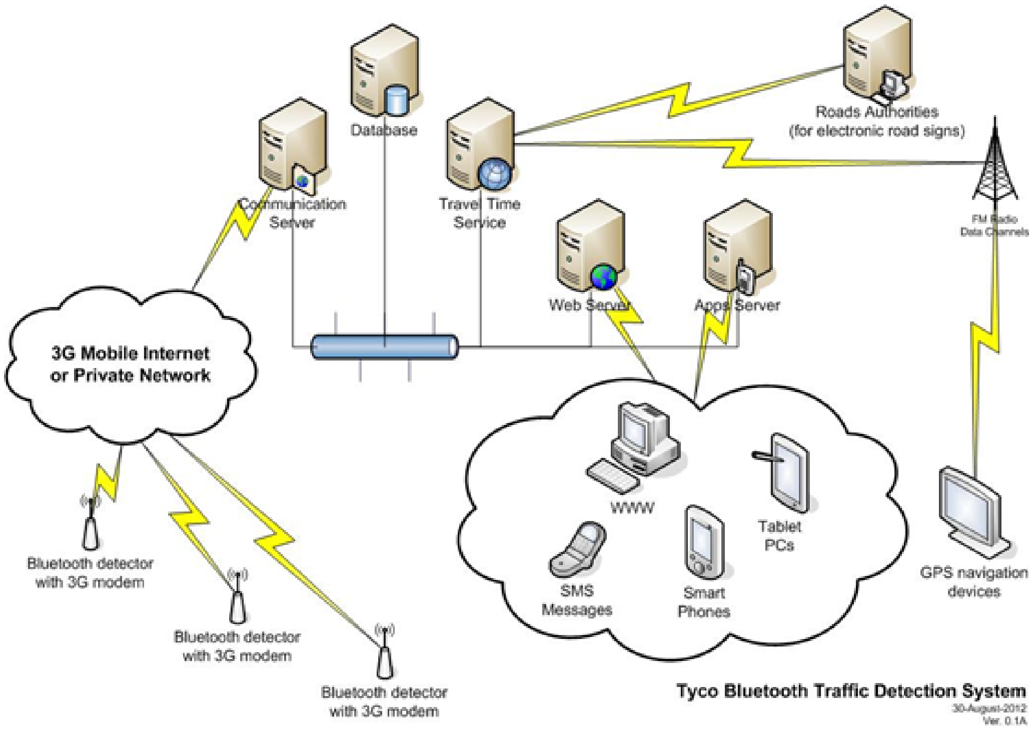

Figure 9: An example of a Bluetooth based vehicle detection system – Tyco

During the pairing process between devices and while in 'discovery' mode, Bluetooth transceivers transmit their machine access control (MAC) address which is their electronic identification, and this transmission can be received by the roadside detectors. By detecting the same device multiple times across a transport corridor, traffic monitoring systems can determine vehicle speed and travel time, providing key information for traffic management. [15] The detectors have an issue whereby they are typically unable to detect mobile phones, due to the functionality of 'discovery' mode on the devices. As such, the detectors primarily record Bluetooth enabled devices such as car stereos and hands-free tech, as these typically are always in the 'discovery' mode, and hence can be seen by the roadside equipment. This sadly means the detection system is unable to record older vehicles equipped without such Bluetooth enabled technology. Roadside detectors for detecting Bluetooth signals do so with a high success of detection, with approximately 10% not being detected. Even with this level of detection, if multiple detectors are setup along a road there is a much greater chance of detecting the same vehicle.[16]

2.2.5 Video Analytics: Object Detection and Classification

The use of video analytics has grown at rapid rate over the recent years. Apart from being able to recognize characters, video analytics and artificial intelligence can now deliver much more functionality. Convolutional Neural Networks (CNN) is a state-of-the-art deep learning algorithm that can be trained to differentiate objects by breaking down images into smaller parts and recognising edges, spots and where possible the relationship between them, to identify and classify objects. Such technology is now being used in smart phones for facial recognition. In other industries such as healthcare, imaging analytics is being used to analyse images from patients and detect abnormalities. Zheng *et al*[17] proposed a Deep Convolutional Neural Network (DCNN) for vehicle classification. In carrying out an experiment,

[15] Haghani, A. and Hamedi, M. (2013) Application of Bluetooth Technology in Traffic Detection, Surveillance, and Traffic Management, *Journal of Intelligent Transportation Systems*, Volume 17, Pages 107-109.
[16] Addinsight (2017) Bluetooth or WiFi Scanners for Probe Data Collection – Which is the Best? AddInsight, 17 October 2017
[17] Zheng, H., Gu, N. and Zhang, X. (2018) An Efficient and Slight Convolutional Neural Network for Vehicle Type Classification. Journal of Physics: Conference Series. 2018.

six classes of vehicles: bus, microbus, minivan, sedan, SUV and truck were set with 9850 images used. As a result, the proposed DCNN-based vehicle type classification attained 96 percent reading accuracy compared to a CNN accuracy rate of 84.25 percent over 8 different vehicle categories.[18]

According Zhang *et al*[19], there is a realistic potential to perform real-time, video-based vehicle detection and classification (VVDC) using existing uncalibrated video cameras. This proposed method would utilise available surveillance cameras on road networks, to provide live video feeds to an external algorithm capable of processing digitised images and live video streams. The prototype system could perform vehicle detection, shadow removal and length-based classification of small vehicle (SV) and long vehicle (LV) volumes for each lane on roadways. The prototype system encountered significant issues caused by periodical heavy traffic generating unexpected longitudinal occlusions, severe camera vibration, and headlight reflection problems. Further improvements to VVDC need to be made to improve the overall system robustness. The ability to utilize existing infrastructure is critical to for keeping costs down, however, additional multiuse roadside cameras would need to be installed on roads to increase network coverage and effectiveness of real-time video-based vehicle detection and classification.

Technology companies such as Aero Ranger, Axis, intuVision, Intelligence Integrated Video, and Traffic Vision currently provide traffic video analytics in an attempt to assist with traffic management, such as vehicle detection and counts. The reliability in terms of speed, accuracy and traffic management results are however not provided. Figure 8 provides a screenshot of Aero Ranger's automatic plate number recognition solution that not only detects the vehicle license plate numbers, but also detects and classifies vehicles and other objects.

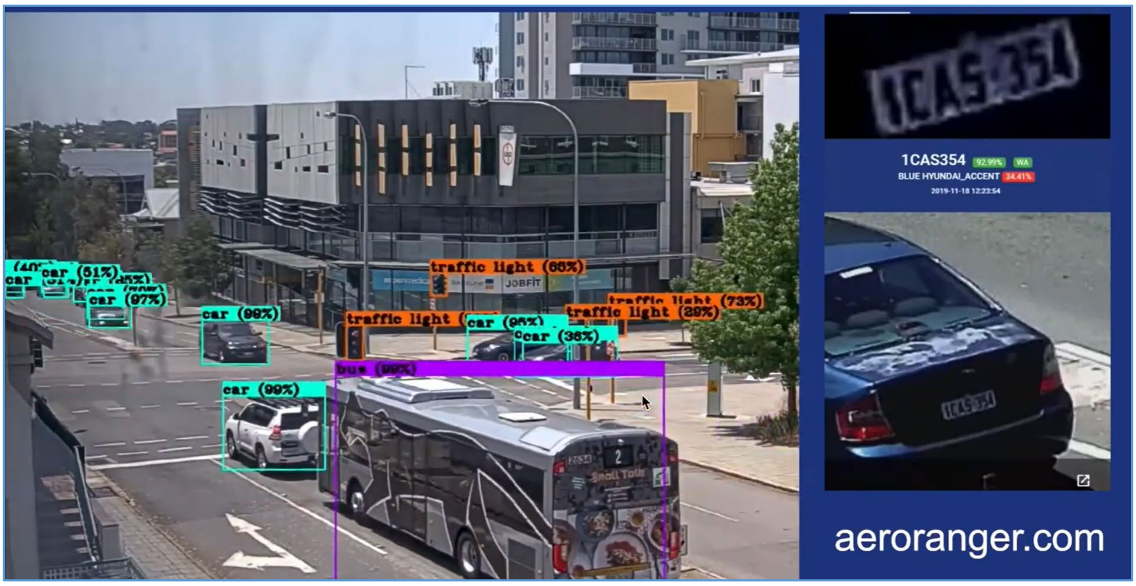

Figure 10: Screenshot of an example of object detection and classification software

This is still relatively new technology with numerous studies being carried out to experiment with different structures and algorithms to identify and classify vehicles, hence the technology can be considered as being in its infancy. In setting up a video analytics-based system for traffic the cameras need to be strategically placed to allow appropriate coverage and vantage, along with being of suitable resolution and low light ability. A typical camera may cost between $1,800 and $3,000 depending on the specifications.

[18] Dongmei, H., Congyan, L., Songhe, F., Xuetao, D. and Zhang, C. (2015) Vehicle detection and classification based on convolutional neural network. In Proceedings of the 7th International Conference on Internet Multimedia Computing and Service (ICIMCS '15). Association for Computing Machinery, New York, NY, USA, Article 3, 1–5.

[19] Zhang, G., Avery, R., and Wang, Y. (2007) Video-Based Vehicle Detection and Classification System for Real-Time Traffic Data Collection Using Uncalibrated Video Cameras. Transportation Research Record. 1993.

2.2.6 Video Analytics: Vehicle Identification using Number Plate Recognition

Using cameras to collect data at fixed points along major routes is another option, although it does not provide comparable data to a GPS tracker. Currently all states use cameras for automatic number plate recognition, mainly by the police to detect stolen or unregistered vehicles and disqualified or suspended drivers. Additional cameras could be deployed at relatively low-cost since this is mature technology. This approach may avoid privacy issues as details of ownership etc. are not required for traffic management and reading details off a vehicle is legal.

The system involves Optical Character Recognition (OCR) applied to CCTV and other video footage to identify the characters displayed on the licence plate of vehicles given the location of the plate is consistent. With technological advancement such as convolutional neural networks and high-resolution cameras the accuracy of OCR technology has increased significantly. Wang *et al* [20] proposed a multi-task convolutional neural network for licence plate detection and recognition to which experimental results have shown an accuracy of 98 percent. On the other hand, solution vendors that are providing readily available OCR technologies such as Vaxtor, a technology company that specializes in optical character recognition (OCR) analytics technology reports an average reading accuracy rate of 98 percent over projects deployed.

[20] Wang, W., Yang, J., Chen, M. and Wang, P. (2019) "A Light CNN for End-to-End Car License Plates Detection and Recognition," in *IEEE Access*, vol. 7, pp. 173875-173883.

PART 3: CONSIDERING FREIGHT VEHICLE INTERACTION WITH TRAFFIC MANAGEMENT SYSTEMS

A potentially valuable benefit of appropriately accessing real time tracking data from freight vehicles (whether from GPS trackers, RFID tags, or cameras) would be to allow interaction with the traffic management system in order to improve traffic conditions for both the vehicles being tracked and the wider transport network.

There are three key aspects to consider:

1. *Receiving and Processing Data*: it is key to understand how data can be used to improve traffic management specifically. This will then inform the selection of which algorithms should be used to process the real-time data and update the traffic signals and other traffic management devices and methods? Can these algorithms be add-ons to existing adaptive traffic signal technology such as SCATS, or are completely new algorithms and hardware required?
2. *Protecting Privacy*: Receiving data from freight vehicle will require appropriate privacy mechanisms to be put in pace to protect drivers and freight operators.
3. *Keeping System Secure*: Connected vehicles and connected traffic signals promise to offer major benefits to reducing congestion, but they are also exposed to major hacking risks; in the extreme case, a hacker could send malicious data resulting in serious collisions, however a series of safety protocols are used in traffic controllers. Any solution developed needs to not only incorporate smart data processing algorithms for optimising the traffic signals, but also needs to be robust against external threats.

An initial review of literature did not identify cases of vehicle platooning or the digital interaction between light vehicles and heavy vehicles along major freight routes. One of the key questions when balancing the needs of light and heavy vehicles is the degree of prioritisation for the heavy vehicles. Should convoys of heavy vehicles receive a completely clear run when they are detected, making all other vehicles wait, or is a different approach required to deliver multiple benefits?

Eilers, Mårtensson *et al* propose a platoon management system concept for heavy-duty vehicles that leverages GPS and vehicle-to-vehicle communication. The proposed system consists of 3 layers: (i) Strategic, (ii) Tactical, and (iii) Operational, each with specific functions. [21]

- *Strategic*: At the strategic level, the system calculates the best route for freight vehicles to reach their destination.
- *Tactical*: At the tactical level, the system scans for freight vehicles that could potentially merge paths and share the same route and calculates the speeds to allow merger of a platoon at a certain location. In a case where vehicles are unable to follow the merger plan suggested due to suboptimal conditions such as heavy traffic, recalculation would take place to potentially merge with the next platoon.
- *Operational*: At the operational level, on-board vehicle-to-vehicle communication is used to share information between vehicles within a same platoon, informing engine management and braking systems.

[21] Eilers, S,. Mårtensson, J., Pettersson, H., Pillado, M., Gallegos, D. and Tobar, M. eds (2015) Towards Co-operative Platoon Management of Heavy-Duty Vehicles. 2015 IEEE 18th International Conference on Intelligent Transportation Systems; 2015 15-18 Sept. 2015.

The proposed concept however, does not interact with traffic management systems to minimize traffic congestion arising from heavy vehicles which could potentially be investigated to further refine the overall movement efficiency of road freights. Companies and academia are increasingly exploring how to make use of AI in traffic management. Since 2018, Transport for London (TfL), a government body responsible for the transport system in Greater London, has been working with Vivacity Labs to investigate the use of surveillance cameras to detect and classify road users i.e. pedestrians, cyclists, trucks, cars, SUVs.[22] Being able to determine volume and types of road users is intended to inform London's traffic management system to allow better management of traffic in real-time.

Another system by Rapid Flow Technologies called 'Surtrac' is an adaptive traffic signal control technology using AI and real time video analytics to better manage intersections, seeking to optimise not only vehicle movement but also the movement of pedestrians and cyclists. As shown in Figure 9 blue rectangles detect cars in the intersection, yellow rectangles detect approaching vehicles, and purple rectangles detect cars heading to the next light. Information collected at each intersection can be shared with neighbouring intersections through dedicated short-range communication devices to improve network flow, along with sending information to vehicles, pedestrians and other ITS systems and sensors. Surtrac has been trialled on over 50 intersections in Pittsburg, Pennsylvania since 2012 and findings suggest that the system helped to reduce travel time by 26 percent, wait time at intersections by 41 percent, and vehicle emissions by 21 percent.[23] Another deployment in Morrill's Corner, one of the busiest intersections in Portland, Maine has seen a 20 percent reduction in delays at the intersection.

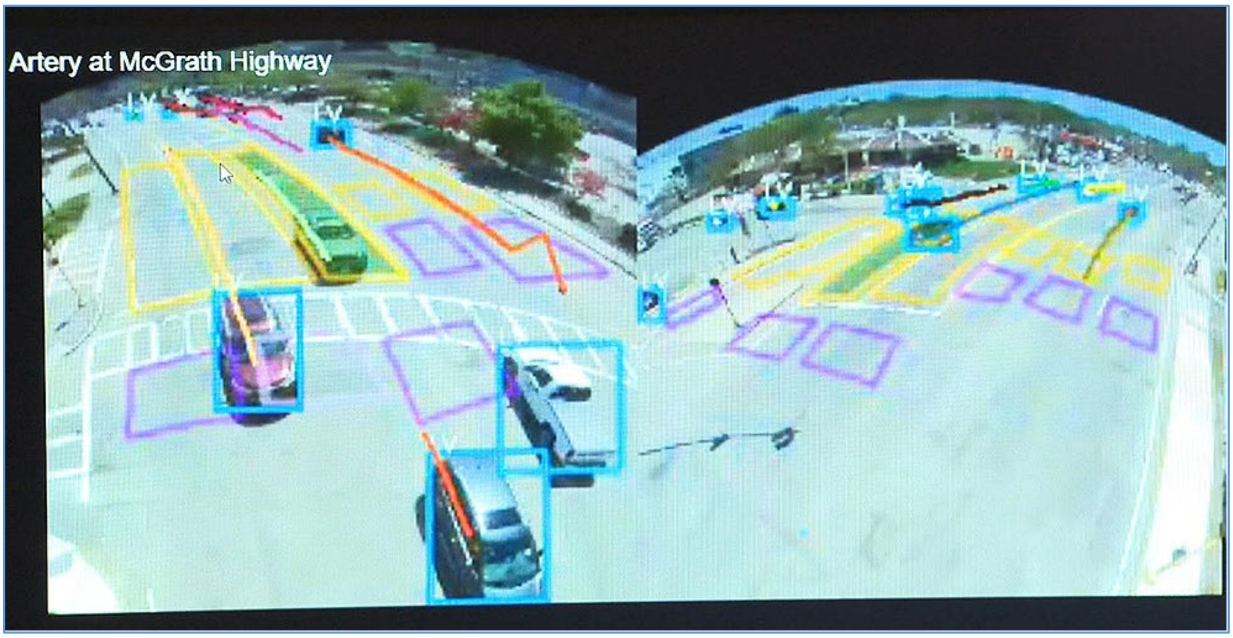

Figure 9: Surtrac Video AnalyticsDisplay

Sun *et al*[24] propose a bus-detection system, including a traffic signal priority algorithm, to prioritise intersection lanes with incoming buses. As a result of simulations, the average wait time for buses was reduced by 16 percent as compared to fixed-time control scheme (which are not often use in Australia). However, the proposed method that prioritizes only buses showed no significant improvement for other road users.

[22] Firmin, C. (2020) "TfL using artificial intelligence to help fuel London's cycling boom", Vivacity
[23] Rapid Flow (2018) "Surtrac Deployment at Urban Grid Networks in Pittsburgh Neighbourhoods", 2018, Rapid Flow
[24] Sun, X., Lu, H. and Wu, J. (2013) Bus detection based on sparse representation for transit signal priority. Neurocomputing. 2013;118:1-9.

Zhao and Ioannou[25] propose a two stage signal control system aimed at optimising signal sequencing to prioritise truck movements. In the first stage the system analyses historical and current traffic conditions to predict future traffic demand and generates an optimal signal sequence. In the second stage priority requests received from approaching trucks are processed in real-time to gather information such as velocity, location, and size of the approaching truck. This is used to alter signal sequencing to provide priority which may include extending or advancing the green phase. The traffic optimisation and priority decision is based off the average weighted sum of all queue lengths at intersections. Simulations suggest a reduction in delay for all vehicles of up to 45 percent. However an issue with systems incorporating traffic signal prioritisation from ongoing vehicles is the very late notice of the existence of a truck, limiting what can be done at the particular intersection and potentially interfering with optimal conditions of a group of intersections along a corridor. This then suggests that along with detection and classification of freight vehicles if routing information could also be accessed this would have a much greater utility to traffic management and stand to deliver greater value to both freight operators and the transport network operator.

A key barrier to linking either freight vehicle location or routing data with traffic management systems is the willingness to share such data due to concerns about its potential use by unauthorised parties that may affect competitive advantage, or its potential use to enforce regulatory compliance - however new technologies may provide an answer. Using Blockchain Technology not only can freight operators significantly reduce transaction costs and streamline logistics along the supply chain it can also provide a mechanism for selective sharing of data with specific parties, such as traffic management systems. The government of Australia has recently released a 5 year 'National Blockchain Roadmap' to help drive the adoption of the technology in the country which is likely to uncover numerous benefits for the freight sector.

[25] Zhao, Y., and Ioannou P. (2016) A Traffic Light Signal Control System with Truck Priority, National Science Foundation and University Transportation Center METRANS at University of Southern California. IFAC-PapersOnLine. 2016;49(3):377-82.