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Compare and Contrast of Options to Collect Freight Vehicle Data in Order to Inform Traffic Management Systems

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Abstract: This paper outlines research findings from an investigation into a range of options for generating vehicle data relevant to traffic management systems. 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. This paper will explore a number of different methods to detect, classify, and track vehicles, each having strengths and weaknesses, and each with different levels of accuracy and associated costs. 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 (global positioning system) trackers and RFID (Radio Frequency Identification) Tags or are part of the network infrastructure such as CCTV (Closed Circuit Television) cameras, satellites, mobile phone towers, Wi-Fi receivers and RFID readers. Technology in this space is advancing quickly having started with a focus on infrastructure based sensors and communications devices and more recently shifting to GPS and mobile devices. The paper concludes with an overview of considerations for how data from freight vehicles may interact with traffic management systems for mutual benefit. This new area of research and practice seeks to balance the needs of traffic management systems 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. This research has been developed with funding and support provided by Australia's SBEnrc (Sustainable Built Environment National Research Centre) and its partners.

Key words: Freight vehicles, vehicle generate data, vehicle tracking.

1. Introduction

The purpose of this paper is to present an overview of options to collect and harness data on freight vehicles in order to support traffic management systems to improve conditions for all road users while delivering direct value to freight operators. According to the ABS (Australian Bureau of Statistics) the level of freight carried on public roads is set to increase, as shown in Fig. 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 other road users. Better freight management reduces congestions, leading to less pollution and a range of direct and indirect economic benefits.

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 improving routing, and collaborating with traffic agencies to enhance traffic management for mutual benefit (using AI (Artificial Intelligence) and associated data collection technologies).

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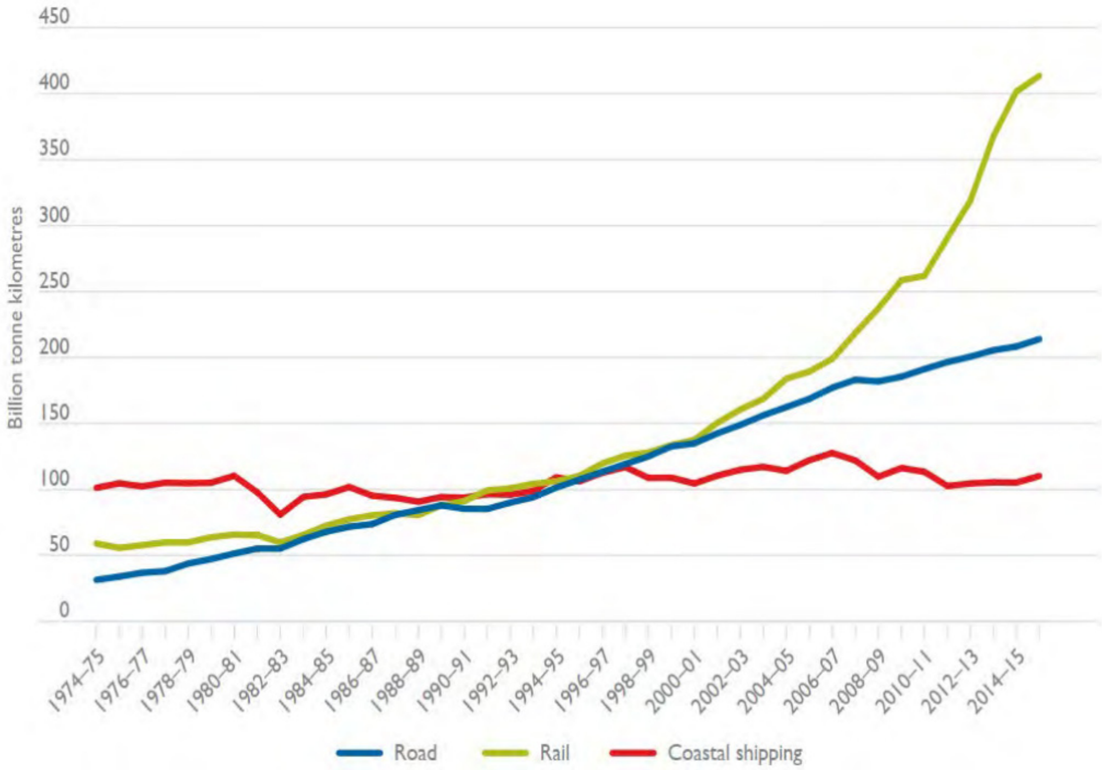

Fig. 1 Changes to the level of Freight in Australia for each main mode.
Source: BITRE (2017) [1].

This paper focuses on the latter 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 (global positioning system) trackers and digital licence plates and RFID (Radio Frequency Identification) technology) and infrastructure-based technologies (including aerial imagery, Wi-Fi, and video analytics), as summarised in Table 1. Following this, the paper considers how such technologies can interact with traffic management, and the associated implications.

Given the need for data standardisation and increased interoperability that are now well understood [2], a key consideration for selecting the appropriate data collection 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 is 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 or technologies embedded in the transport infrastructure.

There are existing technologies embedded into transport infrastructure that are used to manage intersection signalling, such as the SCATS (Sydney Coordinated Adaptive Traffic System) that is used at some 55,000 intersections in 28 countries. The system boasts improvements such as a 28% reduction in travel time, 25% reduction in congestion, 12% reduction in commuter costs, and 15% 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 m 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.

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.

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. 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. 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 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 min if the tracker is moving and every 30 min if it is stationary. The data are then sent to a server to be accessed by fleet managers etc. This can be used in a number of ways including identifying if a vehicle has moved into, or out of, a specified area, referred to as “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.

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

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 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 place 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.
DSRC (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 with a low level of maturity. • Short range capabilities only.
Mobile Network Communications (vehicle tracking and identification)	• A multi-use device allowing a range of functionality, easily updated. • Allows two-way communication. • Readily available, low-cost, non-specialised technology.	• Requires a mobile device to be carried in the vehicle. • 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 min 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.

(Table 1 to be continued)

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.

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 [3].

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

(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.

2.2 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 display 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 allows users to connect to their vehicle through a smart phone application. 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, along with changing the licence plate to read “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 may be 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 is 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 an 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.

2.3 RFID: Vehicle Tracking and Identification

Another method to track vehicles, and any number of other items, is RFID technology, which has been gaining popularity with increasing deployment around the world as part of what is becoming known as AIDC (Automated Identification and Data Capture) technology. In short, an RFID is composed of a digital chip that records data and an antenna (or transponder). 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 (meaning a tag 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 a small burst of data from the chip back through the antenna to the reader, which is quite ingenious.

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 has 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 (identification) number; however, the tags have the potential to send more data and this could include ownership details, vehicle class, plate number, VIN (Vehicle Identification Number) 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. SkyRFID, a Canadian company, provides a passive solution which can be read up to 16 m away and an active solution that can be read up to 3 km away.

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.

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

RFID categories	Type of setup	Frequency	Read range
LF (low frequency)	Passive	125 & 134 kHz	< 50 cm
HF (high frequency)	Passive	13.56 MHz	~1 m
UHF (ultra-high frequency)	Active, passive	433 MHz (active) 860-960 MHz (passive)	~100 m (active) ~10 m (passive)

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)	$1,400-2,800
RFID antennas	$190-600
RFID tags (tags suitable for vehicles)	$15-60

- 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 to be able to reliably read tags on moving objects, i.e. cars and other vehicles 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" [4]. Given RFID technology requires both dedicated tags and receivers it can be a higher cost option for vehicle tracking 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.

2.4 Weight Sensors: Vehicle Weight

Heavy vehicles have varying weights depending on whether they are loaded or unloaded, or their payload type. Given this, using the trucks length or number of axles is not always an accurate depiction of the weight of the truck that can be used for estimating stopping and starting distances at intersections. Along with providing weight and weight distribution details for traffic management systems having weight sensors on each axle can inform loading practices to achieve an even distribution of the weight. For example, a B-Double Truck and Trailer with 9 axles, typically weights 20 tonnes dry, and can weigh as much as 68 tonnes at maximum payload [5], hence if the traffic management system was to respond purely to the number of axles it would not be able to identify if it was full or empty, which affects breaking and acceleration of the vehicle. The ability for a truck to accelerate and decelerate is greatly affected by its weight, having and being able to communicate this information to the upcoming traffic light, or in fact to the traffic management system, 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 from 0 to 60 km/h in 55 s [6], whereas a 68 tonne B-double, takes 71 s to accelerate from 0 to 60 km/h, if weight sensor, 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 would not be taken into account.

2.5 Onboard Wi-Fi (DSRC): Vehicle Detection

DSRC is a wireless technology that allows vehicles to communicate with other vehicles or with infrastructure over short to medium distances. Operating most commonly over the 5.9 GHz radio frequency band [7], vehicles are fitted with on-board units and roadside units are installed to share road and traffic conditions. DSRC is a fast and highly secure technology with data only relayed when the units are within range of each other. These units enable V2V (vehicle-to-vehicle), V2I (vehicle-to-infrastructure) and V2X (vehicle-to-everything) communications, allowing vehicles and traffic systems to be better managed [8]. Cohda Wireless has been involved in numerous vehicle detection projects such as the Cohda V2X Locate trial in New York City. This trial compared the performance of roadside and on-board units against a high-quality GNSS (global navigation satellite system), which can experience "blackspots" due to obstructions created by buildings. The trial found that 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 1 m. 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 [9].

2.6 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. Along with typical data such as location, route, and speed, such a device is capable of reporting on fatigue management, navigation, incident reporting, messaging, and fuel use, transmitted 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, along with the ability to provide preferential passage, presents a valuable opportunity for both freight carriers and traffic system managers [10]. The use of mobile devices also allows data access to be controlled, such as being muted or turned off when the device is not on route. Further the use of a mobile device 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, stevedore bookings, 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 compared to other on-board technologies. 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 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 compared to say WiFi or Bluetooth that can pick up mobile devices used by private drivers, walkers, cyclists, and those using shared modes [11].

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.

3. Roadside Infrastructure Based Technology Options

3.1 Aerial Imagery: Object Detection

Satellite images combined with AI provides another method of detection and classification of vehicles. The approach segments different objects, such as vehicles, for classification with up to 80% 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 min, which would not be sufficient for traffic management. Another challenge would be identifying vehicles with obstructed line of sight, such as overpasses, gantries and trees. Vehicles in tunnels are, needless to say, out of sight and will not be detected. This method may be a viable option in the future when the technology can provide real-time data and avoiding roadside infrastructure.

3.2 TIRTL (The Infra-Red Traffic Logger): Vehicle Detection

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 over-height vehicle detection, toll systems, traffic monitoring, speed and incident detection systems, the technology is in operation in numerous cities. The TIRTL system detects trucks using the number of axles, the vehicle length, or the height of the vehicle as it approaches an intersection, and depending on the speed, can affect the timing of the traffic 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 similarly to a Wi-Fi signal based system. However the TIRTL system performs better in extreme weather events. The 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 min per logger.

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

3.3 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 [12]. The system uses a CNN (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 (sport utility vehicle), pickup trucks, and large trucks with an accuracy of 82.4% for both lanes combined, compared to 96% 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 few 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.

3.4 Bluetooth Signals: Vehicle Detection and Speed

It is possible to detect Bluetooth signals in vehicles using roadside equipment for use in detecting vehicles and vehicle speed. The roadside detectors are typically spaced at 50 m intervals and detect the vehicle's MAC (machine access control) address at multiple locations to estimate speed. During the pairing process between devices and while in "discovery" mode, Bluetooth transceivers transmit their 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 estimate vehicle speed and travel time, providing key information for traffic management [13]. The detectors have an issue as 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, headphones etc. as these typically are always in the "discovery" mode, and hence can be seen by the roadside equipment. This 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 90% of enabled vehicles being detected [14].

3.5 Video Analytics: Object Detection and Classification

The use of video analytics has grown rapidly in recent years. Apart from being able to recognize characters, video analytics and AI can now deliver much more functionality. 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, shapes 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. [15] proposed a DCNN (deep convolutional neural network) for vehicle classification. In carrying out an experiment, six classes of vehicles: bus, microbus, minivan, sedan, SUV and truck were set with 9,850 images used. As a result, the proposed DCNN-based vehicle type classification attained 96% reading accuracy compared to a CNN accuracy rate of 84.25% over 8 different vehicle categories [16].

According to Zhang et al. [17], there is a realistic potential to perform real-time, VVDC (video-based vehicle detection and classification) using existing un-calibrated video cameras. This proposed method would utilise available surveillance cameras on road networks to provide live video feeds to an algorithm capable of processing digitised images and live video streams. The prototype system could perform vehicle detection and length-based classification of small vehicles and long vehicles 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 for keeping costs down, however, additional multi-use roadside cameras would need to be installed on roads to increase network coverage and the effectiveness of real-time VVDC.

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. Video analytics is a 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.

3.6 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 cameras are often used 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 if often deemed legal in this case. The system involves OCR (optical character recognition) 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 CNNs and high-resolution cameras the accuracy of OCR technology has increased significantly. Wang et al. [18] proposed a multi-task CNN for licence plate detection and recognition to which experimental results have shown an accuracy of 98%.

4. Considering Freight Vehicle Interaction with Traffic Management Systems

A potentially valuable benefit of appropriately accessing real-time tracking data from freight vehicles 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 important to understand how data can be used to improve traffic management and to select appropriate algorithms to process the real-time data and update the traffic signals and other traffic management devices and methods. An initial question will be weather such algorithms can be add-ons to existing adaptive traffic signal technology such as SCATS, or if they require new systems.

(2) Protecting Privacy

Receiving data from freight vehicles will require appropriate privacy mechanisms to be put in pace to protect drivers and freight operators. Such data may be inappropriately used by competitors or may be used for punitive measures by government agencies. Hence it will be important that such data are released and used under strict consent agreements.

(3) Keeping System Secure

Connecting vehicles to traffic management systems promises to deliver reductions in congestion, improved network utilization, enhanced transport planning, however such data must be secure to avoid malicious actors sabotaging the signalling system. Hence such a solution would need to both incorporate smart data processing algorithms for optimising signalling along with being robust against external threats.

One of the key questions when balancing the needs of light and heavy vehicles is the degree of prioritisation for the heavy vehicles, with logistics operators preferring prioritisation for freight vehicles and the road using public being wary of such measures. The question becomes: should convoys of heavy vehicles receive a clear run of green lights and cause delay to all other vehicles or is a different approach required to deliver multiple benefits? Eilers et al. [19] propose such an alternative approach to platoon management for heavy-duty vehicles that leverages GPS and V2V communication. The proposed system consists of 3 layers: (i) strategic, (ii) tactical, and (iii) operational, each with specific functions and would require information on real-time location and intended destination.

- Strategic: At the strategic level, the system calculates the best route for freight vehicles to traverse the transport network and 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 mergers of freight vehicles at certain locations. 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 opportunity to platoon.
- Operational: At the operational level, on-board V2V communication is used to share information between vehicles within a same platoon, informing engine management and braking systems.

The proposed concept however, does not interact with traffic management systems to minimize traffic congestion, something that may require AI applications, with companies and academia increasingly exploring how to make use of AI in traffic management [20]. Since 2018, TfL (Transport for London), 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 [21]. 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 intersect ions, seeking to optimise not only vehicle movement but also the movement of pedestrians and cyclists. In such a system 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 (Intelligent Transport Systems) systems and sensors. Surtrac has been trialled on over 50 intersections in Pittsburgh, Pennsylvania since 2012 and findings suggest that the system helped to reduce travel time by 26%, wait time at intersections by 41%, and vehicle emissions by 21% due to reduced idle time [22]. Sun et al. [23] proposed 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% as compared to fixed-time control scheme. However, the proposed method that prioritizes buses showed little to no improvement for other road users.

As an advance to these programs, Zhao and Ioannou [24] proposed a two-stage signal control system aimed at optimising signal sequencing to prioritise freight vehicle movements. In the first stage the system compares historic traffic data with current traffic conditions to inform predictions of near-future traffic demand and generates an optimal signal sequence. In the second stage priority requests received at intersections from approaching trucks are processed to gather information such as velocity, location, and size of the approaching truck. This is used to alter signal sequencing, which may include extending or advancing the green phase, considering the average weighted queue lengths at intersections with simulations suggesting a potential reduction in delay for all vehicles of up to 45%. However an issue with systems that allow traffic signal prioritisation for oncoming vehicles is that the very late notice limits what can be done at the particular intersection, and more widely may potentially interfere with conditions in surrounding intersections and the local area of the transport network. Hence, 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 [25].

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 not otherwise be possible—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 under appropriate consent agreements.

5. Conclusion

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 (as summarised in Table 1) and each with different levels of accuracy and associated costs. This paper has provided an overview of such technologies, considering both on-board devices, such as GPS, along with equipment that is required to be embedded in roadside infrastructure, such as Bluetooth, Wi-Fi and CCTV with video analytics. Technology in this space is advancing quickly and initially focused on roadside sensors and communication devices before shifting, more recently to on-board devices, such as GPS and mobile devices.

A key consideration in selecting the most appropriate form of data collection is the required latency (or delay in sending and receiving), with two main options. The first involves applications that require ultra-low latency data, meaning almost immediate transfer of data, such as collision avoidance and other safety applications. The second involves applications that can handle a small delay in the receipt of data, such as traffic management. It is likely that much of the data in the first type will need to be shared quickly from V2V over short ranges to avoid safety concerns. 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.

A key learning from the research 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 and destination 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, most likely requiring new AI applications [20]. It is envisaged that in the not too distant future the majority of vehicles will provide some form of data to the traffic management system to allow better functioning of the transport network, however, the form of the 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 have not been available in the past, current traffic management systems typically are not yet appropriately equipped to process the data and provide network-wide benefits in real time, with such capacity needing to be developed in stages.

It is recommended that further research be undertaken to support a transition over time to allow seamless disclosure by freight and other large or heavy vehicles of data such as vehicle classification, location, and intended route. This will involve providing an appropriate assurance that data will be used only as intended, demonstrating and delivering value to both freight operators and transport network managers, and progressively increasing the capacity of traffic management systems to use such data in transport network management and planning.

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