International best practice digitisation in transport and freight

Lessons for Australia

Final Report
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International best practice digitisation in transport and freight: Lessons for Australia

Final report

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The Commonwealth of Australia, represented by the Department of Infrastructure, Transport, Regional Development and Communications

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***List of** acronyms, **abbreviations** and initialisms*

ABS	Australian Bureau of Statistics
AI	artificial intelligence
AIS	Automatic Identification System
AMR/s	Autonomous Mobile Robot/s
AR	augmented reality
AVL	automatic vehicle location
B2B	business-to-business
B2C	business-to-commerce
BART	Bay Area Rapid Transit
BCARR	Bureau of Communications, Arts and Regional Research
BCR/s	benefit-cost-ratio/s
BITRE	Bureau of Infrastructure and Transport Research Economics
CAV/s	connected and automated vehicle/s
CBA	cost-benefit analysis
CCTV	closed-circuit television
C-ITS	Cooperative Intelligent Transport Systems
CRM	customer relationship management
DITRDC	Department of Infrastructure, Transport, Regional Development and Communications
DLT	distributed ledger technologies
EDI	Electronic Data Interchange
ERP	Electronic Road Pricing
ETC	Electronic Toll Collection
ETCS	European Train Control System
EV/s	electric vehicle/s
GCI	global competitiveness index
GDP	Gross Domestic Product
GHG	greenhouse gas
GPS	Global Positioning System
GSM	Global System For Mobile Communications
HV/s	heavy vehicle/s
ICT	information and communications technologies
IEA	International Energy Agency
IMO	International Maritime Organization
INKA	Innovative Cities

IoT	Internet of Things
ITS	Intelligent Transport Systems
LiDAR	Light Detection and Ranging
MaaS	mobility-as-a-service
Mbps	megabits per second
ML	machine learning
OECD	Organisation for Economic Co-operation and Development
POC/s	proof of concept/s
R&D	Research & Development
RFID	radio frequency identification
RPS	Road Pricing Scheme
SaaS	software as a service
SCATS	Sydney Co-ordinated Adaptive Traffic System
SCOOT	Split Cycle Offset Optimisation Technique
SLR	Systematic Literature Review
SMEs	small and medium sized enterprise/s
TMC/s	transport management centre/s
UAV/s	unmanned aerial vehicle/s
V2X	vehicle-to-everything
V2I	vehicle-to-infrastructure
V2V	vehicle-to-vehicle
VKT	vehicle-kilometres travelled
VMS	variable message signs
VR	virtual reality

Executive summary

Executive summary

A number of measures available in the literature indicate that Australia's transport sector falls behind on digitisation trends compared to many other Organisation for Economic Co-operation and Development (OECD) countries, particularly in terms of the role of information and communications technologies (ICT) in enhancing the performance and efficiency of the transport and freight sectors.

Background

This research undertook a comprehensive review of international best practice in the area of transport and freight digitisation, with a view to understanding how digitisation might enhance these sectors' performance. The research identified learnings from the experience of countries with higher levels of transport and freight digitisation, and how these could be adapted to help Australian decision-makers shape the future directions of innovations in these sectors. Key case studies demonstrating the benefits and impacts in terms of enhancing performance and productivity were analysed. The research also included stakeholder consultations to ensure the findings reflected industry and government experiences of the barriers, opportunities and benefits of digitisation.

Evaluation framework

This study considered all users and transport modes that are part of the transport and freight sectors. These include road, public transport, freight and supply chain management, rail transport, maritime and shipping, active transport and aviation. Within each sector, a number of functional areas that are amenable to digitisation and technology solutions were identified. A total of 40 functional areas were analysed that included road safety, adaptive traffic signal control, managed motorways, public transport management, video surveillance and monitoring, electronic ticketing payment systems, asset and cargo management, train signalling, airport safety and security, predictive asset management, port operations and safety of cyclists and e-scooters. The study also identified key emerging technologies that offer promise in addressing the key challenges facing the transport and freight sectors such as artificial intelligence (AI), CAVs, Internet of Things (IoT) and blockchain. Digitisation best practices in each of the 40 functional areas were evaluated taking into consideration the numerous benefits of tech-enabled smart mobility solutions such as improving safety, productivity, efficiency and user experience. The evaluations showed high benefit-cost-ratios (BCRs) for digitisation solutions compared to expanding physical transport infrastructure. On average, traditional transport capacity expansion projects (such as building new roads or tunnels) provided a BCR below 3.0. This is much lower than the benefits of technology and digitisation solutions that were found to exceed a BCR of 5.0 in many cases and reach as high as BCR of 30 in some cases. Digitisation investments were also found to require much lower capital investment compared to infrastructure building projects.

Benchmarking

This study also included benchmarking of best practice transport and freight digitisation across OECD countries. Comparative evaluations were undertaken based on 10 international digitisation indicators in addition to 40 new indices developed in this research covering all functional areas. This information was used to develop best practice transport and freight digitisation indices based on three pillars that included productivity, industry and consumer acceptance, and policy and regulations. The benchmarking results showed Australia's best practice transport and freight digitisation index to range between a score of 59 for the maritime sector up to a score of 81 for the road sector. Australia's overall index score across all sectors was 72 which ranked Australia at number 13 amongst all OECD countries.

Top 20 OECD countries according to best practice transport and freight digitisation index

OECD country	Road	Public transport	Freight	Aviation	Maritime	Rail	Index	Rank
Korea	84	70	85	83	78	81	80	1
Netherlands	82	70	86	80	80	80	80	2
Japan	82	70	85	81	70	85	79	3
United States	81	69	84	84	74	79	79	4
Switzerland	84	71	82	79	61	86	77	5
United Kingdom	81	67	86	80	73	75	77	6
Germany	81	64	84	80	72	76	76	7
Denmark	81	70	86	74	68	75	76	8
France	81	66	81	79	70	71	75	9
Sweden	82	64	83	72	64	74	73	10
Canada	81	66	80	79	62	71	73	11
Spain	82	62	78	78	70	66	73	12
Australia	81	65	80	78	59	70	72	13
Finland	81	68	81	72	57	72	72	14
Norway	78	71	81	73	52	71	71	15
Belgium	76	61	80	67	71	68	70	16
New Zealand	77	64	75	68	58	67	68	17
Austria	76	63	80	66	46	74	68	18
Luxembourg	74	62	77	61	58	69	67	19
Portugal	79	58	75	66	59	61	66	20

Stakeholder consultations

Key stakeholders were invited to participate in a survey to share their insights on freight and transport digitisation. Responses from 27 senior managers across government and industry showed the top three challenges were related to data (standards, sharing mechanisms and privacy), technology (disparity, accessibility and capability) and the role of government in coordinating digitisation across the industry. Respondents' feedback was positive about the future impacts digitisation could have on the freight and transport industries, with several opportunities identified related to improving productivity.

Policy lessons

Key success factors and policy lessons from countries with high transport and freight digitisation rates were identified. The recurring policy themes in these countries included:

1. Development of a national vision for transport digitisation
2. Commitment to funding for capital investment and maintenance
3. Fostering partnerships and collaboration between stakeholders
4. Facilitating private investment
5. Promotion of standards
6. Commitment to research and education
7. Removing barriers to innovations and competition
8. Performance-based transport investments informed by BCR analyses.

Recommendations

A number of recommendations are provided to support wider adoption of transport and freight digitisation in Australia. These recommendations aim to enhance the digitisation ecosystem, including policies, regulations and infrastructure requirements, to support a rapid digital transformation in the transport and freight sectors. The recommendations are:

1. Development of a national vision for smart mobility
2. Setting new policies for smart mobility and aligning initiatives with national strategy
3. Supporting translational R&D and testing of new promising technologies
4. Investment in backbone digital infrastructure must be considered with transport digitisation
5. Investment in human, organisational and institutional learning and capacity building
6. Development of statewide integrated smart mobility operations centres
7. Development of agreed standards and interoperability to improve data sharing

Finally, this study outlined potential future directions targeting initiatives to accelerate deployment of transport and freight digitisation in Australia, including research to address data gaps, and development of a national transdisciplinary smart mobility research agenda.

Introduction

Introduction

This research undertakes a comprehensive literature review of international best practice in digitisation in the transport and freight sectors. Key case studies demonstrating the benefits and impacts in terms of enhancing network performance, efficiency and productivity will be identified and analysed. It will also use a framework to document how increased digitisation of the transport and freight sectors has the potential to improve system resilience and produce economic productivity gains. The learnings that will be identified from successful experiences in countries with higher levels of transport digitisation will help Australian decision-makers shape the policies and regulations that are required to drive the use of digitisation in Australia's transport and freight sectors.

The research will also include key stakeholder consultations to ensure the findings reflect industry and government experiences of the barriers, opportunities and benefits of digitisation across all users and transport modes, including road, rail, maritime, and aviation, which are part of the transport and freight sectors.

Research background

A number of measures available in the literature indicate Australia's transport sector falls behind on digitisation trends compared to many other OECD countries, particularly in terms of the role of ICT in enhancing the performance and efficiency of the transport and freight sectors. Some domestic indicators also show the transport sector has experienced slower rates of digital activity and innovation compared to many other sectors in Australia. According to the Australian Bureau of Statistics (ABS), in 2018-19, businesses in the transport, postal and warehousing sector had the second lowest level of innovation compared to other businesses surveyed (ABS, 2020). These statistics showed that only 35.6% of Australian businesses in this sector were innovation-active compared to 60.9% in the wholesale trade, 59.5% in manufacturing and 47.5% in arts and recreation services. While there doesn't appear to be strong evidence for why digitalisation is lower in the transport sector, the latest ABS Business Characteristics Survey (2019-20) found that internet speeds, uncertainty of benefits, insufficient knowledge and lack of skills were the biggest barriers to the use of ICT by transport sector businesses, but over 60% of businesses surveyed identified no limiting factors (ABS, 2021).

This project has undertaken a comprehensive review of international best practice in the area of digitisation with a view to understanding how it might enhance transport and freight efficiency and productivity. The research will also identify the learnings from the experience of countries with higher levels of transport and freight digitisation and how these could be adapted to help Australian decision-makers shape the policies and regulations required to drive the use of digitisation in Australia's transport and freight sectors. The learnings from this research will also help to identify the barriers that have to date resulted in low digitalisation in Australian transport sector businesses and how these barriers can be overcome. Policy and regulatory opportunities will be also considered comprehensively, with openness towards considering well-established as well as innovative and emerging approaches.

For the purposes of this research, 'digitisation' and 'digitalisation' are used interchangeably and both refer to the uptake of digital technologies, digital infrastructure and digital services, and the enhancement of digital capabilities, supported by data and digital-ready regulatory frameworks.

Research objectives

Successful completion of this research will help the Department of Infrastructure, Transport, Regional Development and Communications (DITRDC) form a deeper understanding of the current state of developments, emerging trends and future directions where governments may have a role in improving the use of digitisation in transport and freight across different modes and uses in Australia in the short, medium and long-term horizons.

Specifically, the research will analyse and discuss the role of these technologies and digital solutions in improving the safety, efficiency, productivity, accessibility and resilience of transport and freight systems across all modes, and the required market adoption rates and levels of digitisation required to have a lasting and meaningful impact on performance. The study will also investigate how disruptive mobility solutions are likely to impact the transport industry with new business models and opportunities that may be introduced on digital platforms.

Importantly, the study will also identify policies and regulatory and legal enablers expected to increase the effective use of digitisation in a rapidly evolving and continuously changing field. This study will aim to identify policy levers that could maximise the social and economic benefits that digitisation will enable, while minimising any potential adverse effects or disadvantages.

The research is informed by international case studies and lessons learnt from a number of countries (including Japan, Singapore and South Korea, amongst other countries) who are recognised as key leaders in this space and have already introduced legislation and facilitated regulatory environments and investment opportunities for largescale adoption.

Finally, the research will identify how the department and key stakeholders can continue to monitor and be kept abreast of developments. It will also identify potential partnering opportunities with other organisations to conduct future research in relevant key areas.

Research approach

Completion of this research will be focused on desktop studies and stakeholder consultations. The desktop studies will include a comprehensive literature review and environmental scan that systematically surveys and interprets relevant studies to identify the current state of knowledge and technological and socio-economic factors in digital innovations that are driving the transport sector developments, and the opportunities, challenges and barriers that could influence future decisions and deployments in Australia.

The research includes the following key tasks:

1. **Undertake a bibliometric analysis and a comprehensive review of global best practice and innovations in transport and freight**

This research applies a hybrid literature review approach. The hybrid approach combines the conventional techniques of scanning the literature in addition to a Systematic Literature Review (SLR) that involves more analytical techniques to increase the search domain and minimise any potential bias. The conventional techniques of literature scan are first used to uncover the key sectors and digitisation areas in transport and freight. Once these are identified, the SLR methodology is applied to the key sector areas to systematically scan the existing body of knowledge using online indexes and other relevant database to identify all possible sources of information that fit the predetermined search criteria. The collected literature will then be recorded in a database for further analysis and sharing with other stakeholders. This hybrid approach is beneficial to ensure the literature has been collected robustly and the results of analysis are objective, comparable, quantifiable and reliable. This methodology also benefits from sophisticated search engines (e.g. Scopus and Web of

Science), enabling the research team to define inclusion and exclusion criteria to filter and categorise the relevant studies under review. The hybrid review methodology includes a number of key tasks for defining the research questions and goals; defining the inclusion and exclusion criteria; searching the technical databases and extracting relevant content.

2. **Use the SLR findings to provide a global snapshot of the current state of transport and freight digitisation**

In this task, the findings and results from the SLR are used to obtain insights about the current state of development, the emerging trends and the directions driving future developments in this field. This task also includes a high-level quantitative assessment of the comparative levels of digitisation across different countries (including Australia) and transport modes (including road, maritime, rail and aviation), and the resulting effect on performance. This quantitative assessment will be informed by the SLR framework for understanding best practice as was described above. The SLR findings will be classified into three distinct categories: (1) The current state of technology-driven transport and freight innovations particularly as related (but not limited to) intelligent transport and infrastructure systems; (2) Drivers of emerging technology and digital innovations transport and freight trends; and (3) Disruptive transport and freight solutions and business models.

3. **Review and document best practice transport and freight digitisation case studies**

This research also identifies key global case studies which will be reviewed and examined to identify learnings, success factors and pitfalls to avoid. Specifically, case studies from countries with high levels of transport and freight digitisation will be examined to gain insights about the national policies, programs, agile regulatory frameworks, technical standards and interoperability, research and development (R&D) funding and investments, public-private partnerships, trials and experiments and other key success factors that could be applied in Australia more broadly. These case studies will help to identify potential challenges as well as opportunities for incorporating digital technologies, innovations, processes and systems in transport and freight in Australia.

4. **Identify, in consultation with stakeholders, policy pathways to encourage digitisation in transport and freight**

This task will leverage the SLR findings, the learnings from the reported case studies, and our understanding of the Australian transport landscape to identify and address potential barriers to implementation of best practice transport and freight digitisation across Australia. This task will have regard to whether any country-specific factors would pose materially different challenges and opportunities to the successful use of digitisation in transport and freight. Importantly, this task will include consultations with Australian stakeholders, including government and industry, to gain further insights into the Australian landscape and market drivers.

Literature review methodology

This study adopts a hybrid literature review approach that scans both academic and industry bodies of knowledge using online indexes and relevant databases to identify key sources of information that fit predetermined search criteria. The scan of academic and research literature relies on an established SLR approach using the Scopus database. This approach (**Figure 1**) is beneficial to ensure the literature has been collected robustly and the results of analysis are objective, comparable, quantifiable and reliable. This methodology also benefits from the sophisticated Scopus search engine.

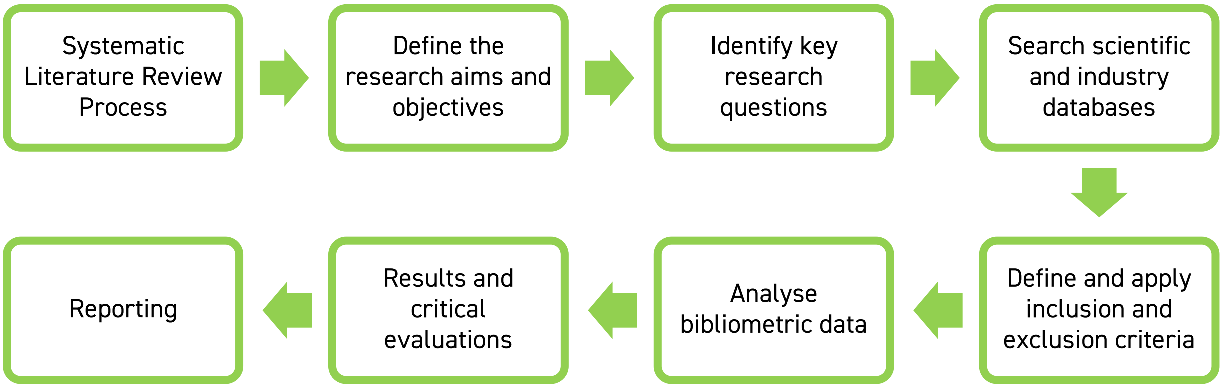

Figure 1: Bibliometric SLR framework

The SLR methodology includes a number of key tasks, such as defining the research questions and goals; defining the inclusion and exclusion criteria; searching the technical databases and extracting relevant content and data; and assessing the quality of results and undertaking analysis and critical evaluations.

Key research questions

The literature review is undertaken to uncover relevant studies that can be used to answer a number of questions, including:

- What are the key challenges facing the transport and freight sectors around the world?
- What are the primary responses to address these challenges and their effectiveness?
- What is the role of technology in addressing these challenges, and what are the key established and emerging enabling technologies?
- What is the current state of knowledge, practice and applications in transport digitisation?
- Who are the key players (e.g. countries and organisations) in the transport and freight digitalisation fields?
- What are the success factors, barriers that must be overcome and pathways to enable widespread deployment?

Inclusion and exclusion search criteria

- Analysis horizon (January 2010 – September 2021)
- Peer-reviewed studies (for reliability and rigour) supplemented by robust industry reports
- Includes digitisation of supply chains and processes
- Includes all modes of transport (road, rail, maritime and aviation)

Data sources

The key data sources used for the review include:

1. Scopus and Web of Science databases. These databases cover academic and research publications including journal articles, conference papers, books and book chapters
2. Industry and other public sources which cover industry technical reports (**Table 1**).

Table 1: Key industry and public data sources

Airport Technology News https://www.airport-technology.com/news/	Global Maritime Hub	Porte Brown
Alliance for Logistics Innovation through Collaboration in Europe	IATA	Railway Technology News https://www.railway-technology.com/news/
Association of American Railroads	IBIS World	Report Linker
Atkins	IBM Center for Applied Insights	Shared Micro Mobility
Austrade	International Energy Agency (IEA)	Shared mobility hub
Australasian Railway Association	IEEE Spectrum	Ship Technology News https://www.ship-technology.com/news/
Australian Government – Australian Institute of Health and Welfare – Reports and Data	iMOVE CRC	Supply Chain Digital
Austroads	Institute for Sensible Transport	Thales Group
Bureau of Infrastructure and Transport Research Economics (BITRE)	IEA	The transportation systems management and operations TSMO
City of Melbourne	International Transport Forum (ITF)	Ti insights
Cogoport Blogs	Lean Supply Solutions	Traffic Technology International (TTI)
CSIRO and Data61	LinkedIn	Transport and Environment
Department of Infrastructure, Transport	Lloyd's List	Transportation Research Board
Departments of transportation technical reports	Maritime Digital	UITP (Union Internationale des Transports Publics) or International Association of Public Transport
Electronic Specifier	Market Research Reports	United Nations Conference on Trade and Development UNCTAD – United Nations publication
EMIS	Medium	Victoria State Government – Department of Transport
Euromonitor International	National Industry Insights	Victorian Government Auditor-General Reports
Federal Highway Administration	National Transport Commission	Victorian Transport Association
Forbes	OECD i-Library	World Bank Group
Fraunhofer Center for Maritime Logistics and Services	Passenger Terminal Today News https://www.passengerterminaltoday.com/news	World Economic Forum
Global consulting firms	PIARC (World Road Association)	World Finance
Global departments of transport technical reports	Port Technology News https://www.porttechnology.org/	

This progress report presents preliminary findings from the literature review task and outlines how the preliminary findings of the review have been used to inform the project's directions and remaining tasks.

Project context

Project context

This research aims to provide direct practical outcomes for Australia based on learnings from international best practices in digitisation of transport and freight. The literature review completed has helped the research team to position this project in the context of global developments as described next. The report first places the project in a context aligned with global transport challenges, opportunities and emerging trends that can provide immediate, short and long-term solutions that are directly relevant in the Australian context.

The review showed that transport and freight activities in countries around the world still present big challenges to decision-makers and policy makers. Despite years of strong investment in transport infrastructure, passenger transport, mobility and freight solutions, transport and freight sectors are still challenged by high levels of congestion, long travel distances and unreliable travel times (Dia, 2017). These issues are becoming more pressing with rising populations and projections that two thirds of the world's population will live in cities by 2030 (Dobbs et al., 2012). In Australia, it is projected that population size will reach 26-30 million by 2030 (ABS, 2018). This growth will be driven by the increasing prominent role of cities at the national and global stages but is likely to result in profound changes in urban environments and communities, and will place additional strains on the infrastructure required to deliver vital services like transport, energy and communications.

Global transport challenges

Today, transport systems face a large number of challenges, including rising urban populations, congestion, environmental emissions, road crashes and injuries, and ageing transport infrastructure. These challenges occur amidst limited budgets to maintain and upgrade the infrastructure required for resilient and modern transport systems, freight and logistics, and public health. In more recent times, challenges have included pandemics, including the COVID-19 crisis the world is currently witnessing. These challenges are global and they affect fast growing cities and towns in both emerging economies and developed countries (Neumann, 2015; Winston and Mannering, 2014) including Australia. Due to the shared nature of transport infrastructure, the challenges are not unique for personal mobility or freight transport and impact the wider transport ecosystem. In this section of the report, key global challenges summarised from recent review work are presented and discussed (Dia et al, 2020).

Rapid urban population growth

One of the megatrends that will have a profound impact on urban passenger and freight transport is rapid urban population growth. Today, the world's cities make up only 2% of the earth's surface, yet they accommodate more than 54% of the world's population, account for 75% of the energy consumption and are responsible for around 80% of the emissions and pollution (Dia, 2017). According to recent studies, around 30% of the world's economy is controlled by 100 cities. Cities like London and New York, together, account for 40% of the world's market capitalisation (Dobbs et al., 2011). Urban populations continue to increase rapidly. In 2007, the global urban population exceeded the rural population for the first time in history. Since then, urban population has grown steadily until it reached 54% in 2014. The trend is expected to continue such that by 2050, the world will be two thirds urban and roughly one third rural (Nieuwenhuijsen et al., 2017; Wilson, 2012). It is expected that by 2025, around 600 cities will generate 58% of the global Gross Domestic Product (GDP) and will accommodate 25% of the earth's population (Dia, 2017). In transport, the energy consumption is expected to almost double by 2050 to meet the travel demand in the world's future cities if the current travel demand trends continue. As more people move into cities, we need to think of new solutions to make transport more sustainable. Rapid urban growth can have a big impact on our cities and transport infrastructure. As an example, urban population growth in Australia for the 20 year period between 1997 and 2017 was around 1.68% per year (Infrastructure Australia, 2019). However, the growth in the number of kilometres travelled was around 3.64% per year, which is more than double the population growth for the same period. Take Melbourne as an example. At 4.4 million today, Melbourne is predicted to reach 6 million by 2031, 7 million by 2041 and 8 million people by 2051. This has serious implications for decision-makers on where and when transport infrastructure investments would be required. It can also affect decisions on the types of investments.

Road and user safety

Another mega challenge facing the transport and freight sectors is the urgent need to improve road and user safety. Around the world, nearly 1.2 million people lose their lives to road traffic crashes every year (WHO, 2016a; WHO, 2016b). Road crashes are also the main cause of death among those aged 15-29 years (Dia, 2017). Traffic injuries are expected to become one of the leading causes of death by 2030 if nothing is done to curb the current trends. Global traffic crashes also carry a financial cost estimated at more than US$500 billion each year (FIA Foundation, 2016). According to recent studies, around 70-90% of these crashes are caused by human error (Dia, 2017). Advanced vehicle technologies such as automatic braking and lane-control systems can help reduce a large number of these crashes. Significant progress has been achieved in recent years to address road safety through connected and automated vehicle (CAV) technologies, and it is expected that fully autonomous vehicles will further improve road safety when they are fully developed and tested for safe deployment (ITS Australia, 2020). The promise of fully autonomous vehicles is that they will remove humans, who are the main source of error of judgement, from the driving equation. When fully developed, these autonomous vehicles will be underpinned by artificial intelligence (AI) self-driving systems that are trained to reduce or eliminate the errors of judgement of a human driver. In Australia, the leading causes of fatal crashes in Australia are attributed to speeding 31%, alcohol 19%, distraction 18% and fatigue 10%. While vulnerable road users and urban related incidents account for a large proportion of all road crashes in Australia (BITRE, 2020), crashes involving heavy vehicles (HVs) are substantial. According to BITRE (2019), 188 people lost their lives in accidents involving heavy trucks, which was a surge of 19.7% in comparison to 2018. These alarming statistics provide insights into the major causes of crashes and the types of countermeasures, including technology, that should be introduced to deal with these challenges. Furthermore, road and user safety challenges are not unique to roads and motorised vehicles but also to those involved in city logistics work. For example, due to increasing number of safety incidents and widespread non-compliance issues involving food delivery platform workers, the NSW Government has proposed new guidelines to help the industry to fulfil their obligations under the Work Health and Safety Legislation (SafeWork NSW, 2021).

Congestion

Traffic and transport infrastructure congestion is another major challenge facing the world's cities. It is a global problem with high costs to society when delays, emissions, disruptions to commercial vehicle movements and lost productivity are taken into consideration (Dia, 2017). One of the key drivers of congestion is high motorisation rates. This is the result of past policies (and in some cases current practices) that encouraged the use of private motor vehicles. In 2016, the total number of vehicles on the road was 1.32 billion, which is double the number of vehicles over a 20-year period since 1996. A major challenge with motorisation is that vehicle populations are growing much faster in emerging economies and developing countries compared to countries in the developed world. By 2050, it is estimated that an additional 2.5 billion people will move into urban areas (Dia, 2017). Even if a fraction of these people bought or used a private vehicle, traffic congestion would spike and persist. There is also an economic cost to traffic congestion attributed to loss of productivity and direct costs related to stopped traffic such as fuel consumption (Dia, 2017). These costs range between 1-5% of a country's GDP (Dia, 2017). In some cities like Cairo in Egypt, the cost is estimated to be 3.6% of the country's GDP. On a global scale, congestion has increased by around 13% since 2008 (Dia, 2017). In the US, the annual economic cost of traffic congestion in 2019 was around US$27 billion in just three of the most congested cities: New York, Los Angeles and Chicago. New York topped the list with an annual congestion cost around US$11 billion in 2019 (Intrado, 2020). In Australia, the annual cost of road congestion in 2016 was around A$19 billion, and public transport crowding was around A$175 million (Dia, 2017). In 2031, the forecast annual cost of road congestion in Australia will be between A$39 to A$53 billion, and public transport crowding will increase to around A$837 million. An additional 6 million people are expected to move into Australia's four major cities of Melbourne, Sydney, Brisbane and Perth by 2031. This will increase congestion costs further if the current trends continue. In Australia, and despite ongoing investments in transport infrastructure, the 2019 Infrastructure Australia Audit found the huge pipeline of road projects, both underway and planned, will not prevent Melbourne or Sydney becoming severely congested by 2031 (IA, 2019). The cost of congestion in the two cities is expected to double, according to the audit, even when taking into account the expected benefits to flow from A$200 billion in road, rail and public transport projects.

Furthermore, the freight distribution networks are also facing major congestion and bottlenecks. The complexities associated with container value chains have particular challenges, which are causing significant delays, cost pressures and disruptions for importers, exporters, shipping lines, shippers and customers. As demand for container transport surges globally, many ports around the world are experiencing congestion and substantial delays. Container supply chains operate in a cycle, meaning that linear vessels visit a series of ports. Therefore, the performance of container terminals are not necessarily determined by their internal operations, but a domino effect that is caused by other ports and vessels in the cycle. A recent report on 'Comparable Container Port Performance' released by the World Bank (2020) states that, except for Brisbane, all Australian seaports are ranked in the 25% of the worst-performing in terms of container operations globally. A recent analysis by Shipping Australia (2021) estimates that a vessel visiting Australian ports could cost its operator more than A$260,500 per day. Hence, a few days of idling could significantly increase costs for operators and ultimately consumers. Furthermore, as port operations expand, congestion impacts the hinterland and across the transport network that surrounds the port.

Ageing infrastructure

Infrastructure around the world is ageing at a fast pace and this will have implications for how it can support transport and urban mobility. Today, the world's infrastructure continues to expand and currently consists of more than 60 million kilometres of roads, 4 million kilometres of railways, 2 million kilometres of pipeline, and more than 1 million kilometres of underwater internet cables (Khanna, 2016). As the world becomes more linked through this matrix of infrastructure networks, it will be infrastructure connectivity, not sovereignty, which will become the organising principle of globalisation (Khanna, 2016). However, inadequate infrastructure that is poorly maintained would struggle to perform and would not be able to meet the demand for travel (Winston and Mannering, 2014). Without well-maintained infrastructure, the world's cities cannot take part in the global connectivity function. Finally, it is estimated that significant investments are needed every year to upgrade urban infrastructure around the world. The infrastructure gap has been estimated at US$57 trillion over the next 10 years (up to 2030) with transport representing around US$23.8 trillion of that deficit (Dobbs et al, 2013).

Ageing infrastructure also has major implications for supply chain productivity. Growing demand for containerisation and congestion on road infrastructure has highlighted the importance of intermodal transport as a sustainable method of delivering freight. The recent 'Infrastructure Priority List' by Infrastructure Australia (2021) highlights the challenges related to ageing infrastructure. It also identifies several freight-related investment opportunities that are essential to support national and international supply chains, including Western Sydney Freight Line, Rail access to Webb Dock in the Port of Melbourne, Australian Marine Complex infrastructure in WA, Port of Burnie and Hobart Port capacity enhancements. Historically, infrastructure investment decisions for freight and passenger transport have been made in isolation. However, efficient intermodal transport is dependent on well-functioning infrastructure across all transport modes. Although ageing transport infrastructure is a globally common issue, Australia faces particular challenges around the lack of nationally accepted regulations (Infrastructure Australia, 2019).

Environmental emissions

Transport activity is a major source of pollution and currently accounts for half of the world's oil consumption. In Australia, it is the second largest source of greenhouse gas emissions (GHG) after electricity generation (Climate Council, 2018). An international scorecard developed by the American Council for an Energy-Efficient Economy ranked Australia third in terms of vehicle distance travelled per capita globally, which contributes to large emissions per capita. According to the IEA, passenger road transport accounted for 45.1%, freight road transport 29.4%, aviation 11.6%, shipping 10.6%, rail 1% and other modes 2.2% of the total carbon dioxide emission produced by the transport sector in 2018 globally (IEA, 2020). Emissions from land transport, specifically, comprise around three quarters of the global emissions from transport activities. In 2010, 25% of GHG emissions were released by the energy sector, 24% (net emissions) from agriculture, forestry and other land use, 21% by industry, 14% by transport and 6.4% by the building sector. The International Council on Clean Transportation's modelling predicts the world's motor vehicle population will double over the next 20 years, and the effects of growing travel demand and increasing shifts to private motorisation are particularly evident in developing countries (Smit et al. 2009; Dia, 2019). The top 10 countries with the largest transport emissions in 2014 were: US, China, Russia, India, Brazil, Japan, Canada, Germany, Mexico and Iran. Together these countries contributed 53% of global transport emissions in 2014. In Australia, passenger cars account for around half of the transport emissions. For freight, Australia's high dependence on trucks rather than rail or sea freight contributes to an increase in emissions by a factor of three (Laird, 2020). Emissions from transport have increased nearly 60% since 1990 – more than any other sector. According to an international scorecard which compared 23 of the largest energy-using countries, Australia ranked second worst for transport energy efficiency. While this decade is already shaping to be a turbulent period (socially and economically), it is also likely to be a decade of climate action where cities pool their resources and take decisive action.

Another challenge is the environmental impacts of trade-related activity derived from freight transport activity. Globally, freight transport accounts for around 40% of the energy consumed in the transportation sector (WRI, 2019). In recent years, carbon emissions produced by the shipping sector have increased significantly and are becoming a concern due to absence of globally accepted regulatory frameworks and commercially viable carbon reduction technological options. The Fourth Greenhouse Gas Study (2020) released by International Maritime Organization (IMO) reports that GHG emissions produced by the shipping sector (including international, domestic and fishing) have increased from 977 million tonnes in 2012 to 1,076 million tonnes in 2018 (9.6% increase). Some of the key reasons behind the growing share of freight in the global emissions include complex and longer supply chains as the result of global outsourcing; lack of globally accepted regulations for monitoring and control of freight-related emissions; and the cross-jurisdictional nature of freight activity.

Transport systems resilience

Another major transport challenge includes making transport systems resilient to endure the stresses and shocks these systems will face throughout their lifecycle, including natural disasters, human-induced stresses and the impacts of climate change and cybersecurity attacks. In transport, resilience represents the system's ability to resist, absorb, adapt and recover from the effects of a hazard or unexpected harmful event in a timely and efficient manner. While transport professionals can plan and anticipate the possible consequences of a large number of expected events, such as peak hour traffic congestion, the real challenge is planning for sudden, unexpected, and in some cases rare events such as hurricanes, flooding and bushfires, which usually don't give decision-makers sufficient time to respond effectively. Decision-makers usually need to anticipate and plan ahead for two types of events for which they need the transport system to be resilient. The first includes short-term acute stresses which represent shocks or incidents such as road crashes. The second are longer-term events and chronic problems such as rapid population growth as a result of an influx of refugees due to geopolitical tensions, or the gradual effects of climate change, both of which place increasing pressures on infrastructure assets.

One of the most commonly used performance indicators to evaluate the resilience of a transport system is the variation in travel times between certain origins and destinations in the transport network. These variations, if large, can cause short or long-term stresses within the transport network. The type of events that are likely to have impact on travel time variability include:

- events relating to physical road features such as interruptions in traffic flow due to a railway crossing or a geometric bottleneck where for example three lanes of traffic on a motorway are forced to merge into two lanes
- fluctuation in travel demand, for example due to a large number of people leaving a sporting event or concert at the same time and within a very short time period
- unexpected incidents that reduce the capacity of a transport system such as traffic crashes, work zone activity, weather and environmental conditions
- cyber attacks caused by unauthorised third parties that could damage or disrupt the operations of interconnected cyber-physical transport systems.

As transport and freight operations become more digitalised and data-driven, they become more vulnerable to cyber-related risks. Data breaches and cyber attacks on transport and freight systems have increased globally, and particularly in Australia. These could result in significant financial losses and cause a ripple effect on upstream and downstream supply chain processes. Recent examples of such incidents include the Nefilim ransomware attack on Toll Group in 2020 and the NotPetya malware which caused major disruption in AP Moller (Maersk) in 2017.

There are two categories of solutions that can improve resilience. The first category calls for investment in smart technologies through installation of sensors in the field to collect real-time data and measure how the system is operating. These systems apply data analytics to provide predictive capabilities and respond quickly and proactively to short-term stresses rather than reacting to them after they have occurred. The second category looks at long-term infrastructure investments that target the weakest links in the transport system and increase their capacity so they can handle larger demands and prevent major disruptions to the system.

Transport energy provision

Another challenge is the energy provision required to power transport systems. The energy needs of transport systems have for a very long time been sustained through heavy reliance on oil production as a result of dependence on motorisation. However, transport dependency on oil is likely to reduce gradually because the current urban transport business models, and the products that sustain them (such as combustion engine vehicles) will be disrupted by superior technologies and business models such as electric vehicles (EVs), mobility-as-a-service (MaaS), electric autonomous on-demand shared fleets and similar emerging technologies (Heikkilä, 2014; Javanshour et al., 2018; Karl, 2015; McKinsey, 2016). This will have massive implications for energy use and also revenues from fuel excise which may lead the way to user-pay road and congestion pricing models of transport taxation.

Climate change

The interaction and interrelationships between climate change and transport are receiving new attention in current research efforts. While it has been known for a long time that transport affects climate and the environment through motor emissions, recent studies have also explored the inverse relationship in how transport is also affected by climate change, and how to mitigate these impacts. Transport has been identified as particularly vulnerable to extreme weather and climate change. Short-duration and high-intensity rainfall, for example, causes significant disruption to transport operations, and climate change is projected to increase the frequency and intensity of such events. Previous studies have identified that increases in hot days and heat waves, intense rain events and hurricane frequency as factors that have the most significant negative impacts on transport (Dia, 2017).

The list of impacts is extensive, covering structural and material damage of structures and disruption of transport services for users. These impacts also vary according to location of infrastructure relative to waterways, and the types of materials and engineering designs used. The intensity of urban land use also results in urban heat islands that modify the local climate. The solutions and interventions that deal with transport resilience are also applicable to dealing with climate change. To improve resilience of transport systems in urban areas, infrastructure must be adapted to cope with extreme events including climate change.

Public health and pandemics

Another challenge facing urban mobility is the impact on public health including physical health, mental health, overall wellbeing, and liveability of cities (Abu-Lebdeh, 2017). In addition to transport-induced crashes, injuries and pollution impacts, there is a focus in recent years on identifying and dealing with the modern day illnesses such as stress, cardiovascular diseases, physical inactivity and obesity. These transport-related health impacts are found to be mostly significant in the long term. They can be subtle, slow, and persistent (Abu-Lebdeh, 2017). They have traditionally not been dealt with or even identified as transport-related; only recently and just qualitatively, these impacts came to be associated with the subjects of urban form, transport and modern day health problems (Abu-Lebdeh, 2017; Dia, 2017). Finally, cities and towns have now needed to respond to a very recent and real challenge which is the impact of pandemics such as the COVID-19 crisis we are currently experiencing. The pandemic has affected cities around the world in so many profound ways. As countries start to ease lockdowns, many communities are putting in place recovery plans to rebuild lives and promote equality and sustainability. People have adapted their daily lives and habits to fight the spread of the disease. Large numbers of people were able to work from home using teleworking and that has sharply reduced the number of trips on our roads. As restrictions eased, many people have taken up cycling and walking to go about their daily lives, particularly in outer suburbs where people are doing more local shopping. Technology is also helping to rebuild traveller confidence in public transport. Automated passenger counting technologies, thermal video detection and a variety of apps where travellers can book their public transport seats in advance are being explored to help commuters travel safely on public transport.

Logistics and supply chains

Countries around the world are experiencing new transport challenges as the result of growing demand for e-commerce and digital purchasing habits. Associated with this pragmatic shift in shopping behaviour, there is an increasing demand for distribution of goods for both business-to-commerce (B2C) and business-to-business (B2B) customers (Thompson et al., 2019). The importance of effective freight transport systems is further highlighted by the increasing rate of urbanisation as discussed earlier (Russo et al., 2016). In the past, freight transport has largely been neglected in the context of urban transport planning (Gatta et al., 2017) where the focus in transport planning and policy approaches relied on studying travel behaviour of individuals to develop solutions for their mobility needs. Urban freight transport, in particular, comprises a unique ecosystem and comes with challenges that are understudied and principally different to those associated with personal mobility (Lindholm et al., 2012). There is also a high degree of industry fragmentation in terms of operational models and assets. Furthermore, the industry consists of a large number of small service providers operating in a relatively complex regulatory environment (i.e. compliance with local, state and national legislations) (Ballantyne et al., 2013). Unlike line-haul transport, the characteristics of fleets involved in urban freight is similar to those utilised by people for personal mobility and light vehicle transport. Therefore, in such mixed traffic situations, there are limitations for regulating freight flows. In addition, the urban transport task is carried out by players that are predominantly commercially driven, with limited government influence to introduce behavioural changes and market regulation. A key challenge is also around availability and reliability of urban freight data, which are the prerequisites for any attempts of informed transport solutions.

Enabled by digital technologies, convenient payment options and advanced information technology, demand for online shopping and e-commerce has surged significantly in recent years. The global pandemic, and the resultant work-from-home economy, is also seen as a catalyst for the increase in e-commerce activity. The e-commerce value chains comprise a series of interconnected processes that start from upstream manufacturing to the final delivery of goods to the doorstep of customers. While the upstream transport activities related to manufacturing and long-haul movement of goods are performed with higher level of efficiency (i.e. goods move in high volume over long distance), the downstream distribution of goods is typically performed on a one-to-one model (i.e. low volumes of goods move along short distances) or what is commonly known as the last kilometre delivery. A recent publication by the World Economic Forum (2021) on the future of parcel delivery predicts that the increasing e-commerce activity will result in 36% more delivery vehicles in inner city areas by 2030.

Response policies and the role of transport digitalisation

The review has also shown that most of the transport approaches for dealing with transport challenges over the past half century have focused on the supply-side by increasing the capacity of available infrastructure, such as building more roads. This approach has largely met with limited success, particularly in countries where the focus was on road transport without equal attention to investment in other modes of transport, such as public transport, electrification, active transport and digitalisation. The misplaced rationale was that reduced road infrastructure investments will result in congestion, which would impact development and growth. One of the key drawbacks of this traditional response, where demand is predicted and then the infrastructure is built, is the generation of induced travel demand. The theory of induced demand indicates that road improvements, which reduce travel times will attract additional trips that would have not occurred if the road's capacity had not been expanded. If capacity is increased, travel demands will increase until congestion delays encourage more investment. This results in a vicious cycle where more travel prompts governments to build more roads, which get congested again in a very short amount of time.

Over the past three decades, however, substantial effort and progress has been made with the application of advanced technologies in the transport field, particularly in traffic operations and management (Sutandi and Dia, 2005; Dia, 2017). These applications, collectively known as Intelligent Transport Systems (ITS), have had significant impacts in improving traffic conditions and providing travellers with seamless travel experiences. These technologies are expected to continue in development and growth over the next decade. These systems, in the initial stages, were referred to as the three dimensions of technology-enabled solutions that included infrastructure, technology and users (**Figure 2**). These systems collectively aim to use meaningful technology to create smarter mobility for better user experience (Dia, 2019).

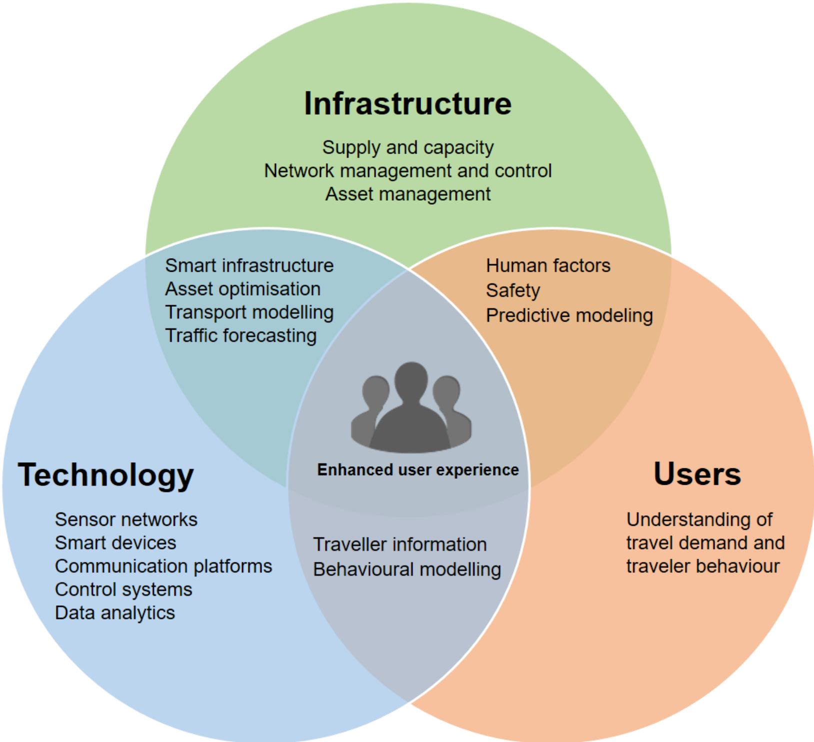

Figure 2: The three dimensions of technology-enabled urban mobility solutions

The motivation behind the ITS movement was a recognition the current travel trends are not sustainable and building additional road capacity is not solving traffic congestion. Increasing levels of congestion and their associated environmental, financial and social impacts prompted think tanks around the world to place more emphasis on improving the efficiency of existing assets through information technologies. Other motivations included limitations of urban space and government budgets, which made it increasingly difficult to upgrade and construct new transport facilities. Technologies such as adaptive traffic control systems and traveller information systems created opportunities to address transport problems through application of communications, and computer software and hardware to all modes of transport. Today, there is increasing evidence (refer to case studies section) these technologies had good outcomes. For instance, they reduced traffic congestion, enhanced network performance, and improved safety and environmental quality by emphasising the efficient utilisation of existing road capacity and transportation infrastructure over building roads (Nigarnjanagoo and Dia, 2005; Panwai and Dia, 2005; Dia et al, 2017).

Traditionally, ITS were primarily classified into three functional areas, which included advanced traffic management systems, advanced traveller information systems and advanced vehicle control systems. Advanced traffic management systems aim to maximise the efficiency of existing infrastructure through better utilisation of existing road capacity (Dia and Gondwe, 2008; Thomas et al., 2001). They include examples such as Sydney Co-ordinated Adaptive Traffic System (SCATS), which offers enhancements to the operation of traffic signals by adjusting signal timings to minimise the overall delays on the road network. Other examples include automated incident detection, motorway ramp control, electronic road pricing (ERP) and dynamic speed control (Dia, 2017).

Advanced traveller information systems aim to influence driver behaviour on departure time, route and mode choice decisions by providing up-to-date real-time travel information (Dia et al., 2001). This information can be provided to travellers either pre-trip or during travel.

Information provided to travellers can include traffic conditions; location of incidents; estimated travel times to destinations; weather conditions (fog, ice, snow); public transportation schedules; and ride-sharing information. This information can be provided to travellers using smartphones, in-vehicle navigation systems and variable message signs (VMS) placed at strategic locations on the road network.

Finally, advanced vehicle control systems aim to improve the safety and efficiency of vehicles, and automating parts of the driving task (Dia, 2017). Most current implementations are designed to allow the driver to override the automatic control at any time. Examples of these systems include collision avoidance, traction and dynamic skid control, adaptive cruise control, and automated parking. The aim of these systems is to produce an intelligent vehicle and relieve the driver of some of the driving tasks. The developments in this space have resulted in a range of new technologies that are now being experimented in the next generation of automated and autonomous vehicles.

It is important to point out that in recent years there has been more focus in ITS R&D on advanced network operations, algorithmic solutions and data-driven management and control of transport systems. There has also been significant new research and progress into the development of smart infrastructure and asset management systems; technology, sensors, communications and control systems; and enhanced personal mobility (Dia, 2017).

Sustainable transport trends

There has been more focus in recent years on the development of sustainable transport systems which meet the needs of people while promoting the community's social, environmental and economic goals and aspirations. This has been partly due to the limitations of the traditional approaches, and also due to a number of emerging trends that have been enabled by advanced technology platforms and new business models (**Figure 3)**. For example, instead of increasing supply and building more roads, the new sustainable approaches focus on managing the demand for travel and maximising the efficiency, reliability and resilience of existing transport systems. Instead of focusing on the physical dimensions of transport, there is increasing focus on the social dimensions and ensuring the benefits of transport projects are equitably distributed across all segments of society. Instead of building infrastructure that is vehicle-oriented, more focus needs to be given for balanced movement of all transport modes. One of the most significant trends, in recent years, has been the impact of the sharing economy and the disruption it is having on the traditional private vehicle ownership model.

Traditional Approaches	Emerging Trends
Focus on supply and building additional infrastructure and capacity	Focus on demand management, maximising efficiency, reliability and resilience of transport systems
Physical dimensions	Social dimensions (mobility benefits are equally and fairly distributed; fair access to transport services for all income groups)
Focus on mobility or physical movement from an origin to a destination	Accessibility: Focus on the mobility required for access to employment, opportunity, goods and services
Large in scale	Local scale - precinct level
Street as road for vehicles	Street as space to be shared between all modes
Vehicle-oriented	People-oriented and customer-focused. Balanced development of all transport modes
Motorised transport	All modes of transport in a hierarchy with priorities for walking and cycling
Transport modelling approaches	Scenario development and modelling
Traffic forecasting	Visioning on cities
Reacting to congestion and disruptions	Focus on positive business and operational outcomes
Travel as a derived demand	Travel as a valued activity as well as a derived demand
Minimisation of travel times	Reliability of travel times
Key performance indicators: Traffic throughput and speeds	Key performance indicators: Accessibility, sustainability, social equity, environmental quality, health and well-being and quality of life
Planning by experts	Planning through transparent and comprehensive stakeholder consultations
Segregation of people and traffic	Integration of people and traffic
Economic evaluation driven by transport efficiency gains	Multi-criteria analysis to take into account environmental and social concerns
Funds raised through petrol taxes, vehicle registration and licensing fees	Congestion and road pricing, and user-pay models
Private car ownership	New business models that promote a shift to car-sharing and ride-sharing solutions enabled by technology platforms
Spending on physical infrastructure	Spending on information technology solutions, data fusion, predictive analytics, integration, decision support systems and adaptive tools
Emphasis on "knowing and seeing", and measuring past performance	Emphasis on "predicting and anticipating" in order to improve resilience and avoid disruptions

Figure 3: Emerging trends and approaches for tackling transport challenges
Source: Dia, 2017

Digitisation framework

Framework for understanding best practice digitisation in transport and freight

The review undertaken was used to develop a framework for understanding the best practice use of digitisation in transport and freight as presented in this section of the report. Applying this framework is helpful for understanding where digitisation has been used effectively in transport and freight. This understanding helps to identify valuable case studies and opportunities for policy makers.

Decision-makers have access to a variety of policy instruments that can steer transport on a path of sustainable development. These include land use, transport and environment integration; human-scale and pedestrian-scale developments; densification; and investments in social infrastructure. In recent years, however, there has been more recognition of the role of digitalisation and smart technologies in enhancing the quality of life of residents through better citizen engagement, enhanced provision of essential services, improved access to economic opportunities, and better utilisation of existing infrastructure and transport assets (ITF, 2015; Batty, 2013).

Many countries around the world have expanded their use of technology in many aspects of life, resulting in a complex network of instrumented and interconnected systems which together provide opportunities for better asset management, including transport assets and supporting infrastructure (Batty, 2013; Kitchin, 2014). Examples of these technologies include IoT sensors, video surveillance, and instrumented assets that communicate with each other to improve infrastructure capability and resilience (Kitchin, 2014). Businesses and governments around the world are also investing heavily in technologies to support predictive analytics, AI, machine learning (ML), and smart infrastructure systems to manage the performance of major assets and detect areas where operations need improvement (Neumann, 2015). These trends are likely to rise in prominence over the next decade to meet citizens' demands for higher quality services in all aspects of their lives.

Although many countries have been applying technology-led solutions in urban transport for more than three decades now (Rose and Dia, 1995; Dia and Rose, 1998), the application of smart technologies and services has only crystallised over the last decade.

Technology-led innovations in transport and freight

In this research study, the framework for digitalisation of transport and freight places sustainability, traveller wellbeing and economic viability at the heart of technology-led innovations (**Figure 4**). In this framework, the policies and objectives of transport and freight are first set by governments through stakeholder consultations resulting in economic, environmental and citizen wellbeing objectives that are commensurate with community expectations. To achieve the desired outcomes, a number of sectors, industries and essential services are identified, and technology becomes an enabler for a smart mobility digital platform that drives delivery of community objectives through digital innovations and enabling technologies that could lead to a transformation of transport services and provision.

For this research study, the analysis of transport digitalisation will first be based on the sectors, industries and services that deliver the policy outcomes for transport (**Figure 4**). It will then identify the functional areas within each sector where technology and digitisation can be applied to enhance performance. In freight, it is acknowledged there will be an inherent overlap between the nature of each transport mode and its role in the freight activity. Therefore, for the purpose of this research, we will present digitisation trends and solutions in each transport mode without separating the mode's role in public mobility or freight markets. A separate analysis is then provided to examine the recent trends in the freight supporting sectors, including logistics and digital supply chain management. The key sectors include:

1. Road transport.
2. Public transport
3. Active transport
4. Rail transport
5. Aviation and air transport
6. Maritime and shipping
7. Freight, logistics and supply chain management

The analysis also details the smart mobility platform and enabling technologies used to transform these sectors through digitalisation. For each transport sector, a range of functional areas where digitalisation can be applied are then identified as shown in **Table 2.**

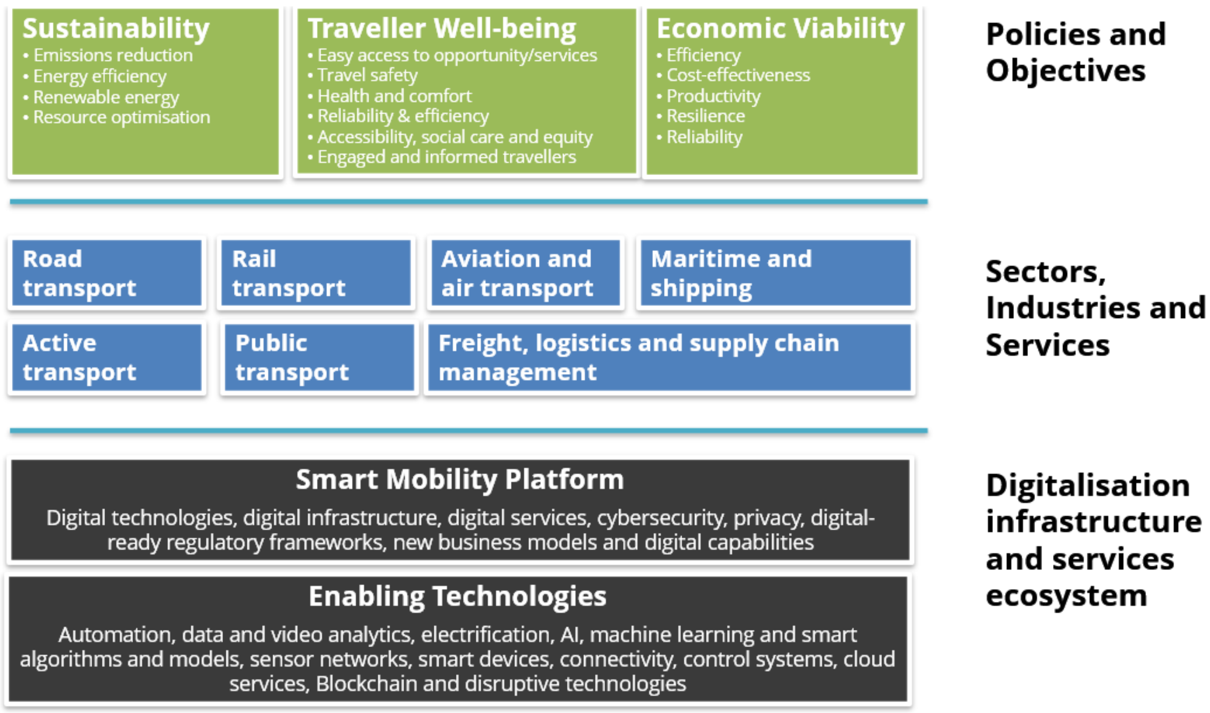

Figure 4: Framework for digitalisation of transport and freight

Road transport sector

The road transport sector includes the movement of people and goods on road-based infrastructure. The key functional areas where digitalisation and advanced technologies are applied are presented in **Table 2** and include road safety, congestion management, adaptive traffic signal control, travel and traveller information systems, network management and control, managed or controlled motorways, and traffic signal priority for on-road public transport and emergency vehicle traffic signal pre-emption.

Public transport sector

This sector includes rail, tram, bus, taxi, and shared ride-hailing forms of transport. Public transport digitalisation and advanced technologies enable platforms and solutions that connect these service modes to meet customers' needs in fully connected networks. Functional areas include passenger and vehicle safety, video surveillance and monitoring, rail traffic management, data management and fusion, shared mobility, security, enforcement and compliance, traveller information systems, access and accessibility, electronic and mobile ticketing, public transport management and multimodal public transport as shown in **Table 2**.

Active transport sector

The active transport sector refers to walking, cycling, scooting and the use of other 'tiny vehicles' for movement of people and goods through small-wheeled, self-propelled or e-devices such as bikes and scooters. **Table 2** presents the main functional areas where digitalisation and advanced technologies are applied, including safety for active transport users and other vulnerable road users, fleet management, parking management and enhanced travel experience.

Rail transport sector

The rail transport sector includes movement of people and goods on vehicles that run on tracks and enables commuting and the movement of carriages over short and long distances. The key functional areas where digitalisation and advanced technologies are applied in the rail transport sector are presented in **Table 2.** These include operations in above-rail (loco and rolling stock) and below-rail (track signalling), terminal operations such as intermodal bulk, quarantine, inspection and compliance, maintenance and engineering services and ICT-based services (e.g. timetabling).

Aviation and air transport

The aviation and air transport sector generates benefits to the broader community by creating virtual bridges and speedy air connections between origins and destinations for the movement of people and goods. The main functional areas where digitalisation and advanced technologies are used in the air transport sector are summarised in **Table 2.** These include airport operations, airport safety/security, capacity management, passenger services, infrastructure services, predictive maintenance, passenger and staff safety and accessibility to/from airports or urban bike-sharing launch pads.

Maritime and shipping

Maritime and shipping is the transport of people and goods through waterways. The key functional areas in this sector where digitalisation and advanced technologies are applied are presented in **Table 2.** These include digitisation of administrative procedures where reporting is currently mostly manual, and improvement of port operations, safety, ocean shipping, short-sea shipping, crew management, supply chain control/visibility, terminal management and intramodality, and cargo and container and maritime traffic management.

Freight, logistics and supply chain management

The freight transport and logistics sector plays a critical role in the seamless movement of materials and finished products in supply chains. The freight and logistics sector is increasingly experiencing new waves of digitalisation that are creating significant changes and transformations to the sector. The functional areas, presented in **Table 2,** include warehousing and contract logistics, last kilometre delivery and urban freight, trade facilitation and documentation, freight forwarding and aggregation, asset and cargo tracking for supply chain visibility, and technology-based services for e-commerce support.

The next sections present descriptions for each of the sectors' functional areas and the range of enabling technologies that are used to enhance the performance of each sector and functional area. It is acknowledged that for each of these functional areas, non-technology solutions are also available. The focus of this research, however, will be on the digital opportunities to transform operations and improve productivity.

Table 2: Functional areas considered for the digitisation of transport and freight

Road sector			
Road safety	Adaptive traffic signal control	Network management and control	Travel information systems
Road-rail intersection safety	Traffic signal priority and pre-emption	Managed motorways	Demand management
Public transport sector			
Safety, security, enforcement and compliance	Video surveillance and monitoring	Electronic and mobile ticketing and payments	Passenger information systems
Personalised public transport and MaaS	Multi modal public transport	Public transport management	Data management and fusion
Freight, logistics and supply chain management sector			
Warehousing and contract logistics	Last kilometre delivery and urban freight	Trade facilitation and documentation	Freight forwarding, aggregation and customs brokerage
Asset and cargo management	Technology-based services for e-commerce support		
Rail sector			
Information and communication technology services	Asset condition monitoring	Operations and track signalling	
Aviation and air transport sector			
Airport safety and security	Airport operations	Capacity management	
Maritime and shipping sector			
Safety and security	Port operations	Administrative procedures	Ocean and short-sea shipping
Maritime traffic management			
Common functional areas across multiple sectors (air, maritime, rail, freight)			
Terminal operations and management	Quarantine and inspection	Infrastructure services and predictive asset maintenance	
Active transport sector (Emerging)			
Safety of riders and vulnerable road users	Parking management	Fleet management	Travel experience

Road transport functional areas

In this research, the road transport sector is classified into the following key functional areas that are amenable to digitalisation and technology applications.

Road safety

In road safety, the application of technologies and digitalisation include both vehicle and infrastructure interventions. These include, but are not limited to, driver fatigue warning, Cooperative Intelligent Transport Systems (C-ITS), intelligent speed adaptation and collision avoidance systems.

Road–rail intersection safety

Road–rail intersection technologies aim to provide improved warning and safety control devices for at-grade crossings where a railway crosses a road at a level crossing. A range of technologies can be used to alert approaching traffic in the case of a potential collision. The intersections can also apply technologies that connect to the control and warning devices at these intersections to coordinate signals. Technology solutions are also used to manage the road–rail intersection equipment and detect any malfunction.

Adaptive traffic signal control

Adaptive traffic signal control systems adjust the timing of green traffic signal cycles according to prevailing traffic conditions. These systems rely on automated data collection using sensors that count vehicles approaching intersections and applying new timing sequences to cater for changing traffic demands.

Traffic signal priority and pre-emption

Traffic signal priority systems are used at intersections to provide extra green time to public transport vehicles, including buses and light rail. Traffic signal pre-emption systems adjust traffic signals to provide safe passage for emergency and other priority vehicles. Both priority and pre-emption systems require equipment on the vehicle and at the intersection to communicate to the traffic signal and request pre-emption or priority. These detection systems detect a vehicle at a single point or within a zone or area and transfer the request to the traffic signal controller.

Network management and control

Road network management and control applications aim to improve the utilisation of road network efficiency through a range of applications and decision support systems. Examples include optimising road infrastructure utilisation through operation of high occupancy vehicle lanes, dynamic express lanes or reversible lanes that adapt to changing traffic conditions and congestion levels. Network control also includes parking management by providing real-time information on utilisation and availability of parking spaces. Network management is supported by a number of enabling technologies including automated data collection from in-pavement or roadside sensors, data analytics, automated incident detection and management, traffic monitoring cameras, traffic signal control and other applications that are coordinated through traffic control centres. Modern traffic control centres also provide for integrated operations of all modes of transport, including operations of public transport and emergency management. This functional area also includes emergency operations where advanced technologies are used for automated incident detection and management, emergency notifications and dispatch of emergency vehicles, and personal security applications. They also include emergency vehicle management, including dynamic route guidance and optimal fleet management.

Managed motorways

Managed motorways include coordinated ramp metering systems supplemented with ramp signals, overhead lane signs, on-road message signs, CCTV cameras and vehicle sensors. These motorways provide an integrated approach that embraces design, ITS and optimised operations. The use of vehicle sensors (such as inductive, buried, loops, radar and CCTV cameras), data processing, and communications technologies help detect and verify incidents quickly. Sophisticated decision support systems are also used to decide on best approaches to respond to any given incident.

Travel information systems

Travel information systems update drivers before and during trips on roadway conditions, including delays, incidents, weather-related messages, travel times, emergency alerts and alternative routes in real-time. These updates allow drivers to make good travel decisions on routes, modes, departure times, and destinations, leading to more efficient roadway capacity utilisation. This travel information is generated by sensors and then reported to a traffic management centre or through private entities using data from in-vehicle location devices or smartphones communicating location and speed. This information is then disseminated via traditional broadcast media, the internet, mobile devices, or roadside messaging.

Demand management

Demand management technologies focus on managing the demand for travel and include road pricing, congestion charging and parking management solutions. Modern demand management systems provide dynamic pricing that respond to changing travel conditions and congestion levels. Other non-pricing technology-based demand management solutions include the use of digital solutions to disseminate information about multimodal transport options available for users and their ease of accessibility. Such information provides travellers with options on the mode and departure time choices, which helps spread travel demand across multiple modes and durations during the day and leads to lower congestion levels, particularly during peak periods.

Public transport functional areas

In this research, the public transport sector is classified into the following key functional areas.

Safety, security, enforcement and compliance

Advanced technologies and digitalisation applications for passenger safety and security include surveillance and monitoring systems, real-time information signs, as well as in-vehicle customer help points. In recent times, video detection and analytics have witnessed a sharp increase in deployment and adoption for passenger safety applications, both outside and inside public transport vehicles. Technological advancements in this area have also focused on improving the safety of public transport vehicles by complementing, or enhancing, drivers' abilities to remain alert and in control of the vehicle, and to improve the crash avoidance capabilities of vehicles. In rail public transport, there have been substantial advances over the past decade in automated and self-driving trains, particularly in underground metros in many cities around the world. Developments in this area are also focused on connected vehicle research, particularly for on-road public transport, and moving towards highly automated or autonomous vehicles, as well as investments in vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication solutions. This functional area also includes enforcement and compliance through applications and digitalisation solutions that aim to improve public transport users', operators' and supporting staff's security, as well as compliance with fare payments enforcement to prevent far evasion. Integrating vehicle location technologies and monitoring systems in security-related incidents provides a warning and response system to deal with such events.

Video surveillance and monitoring

CCTV with image processing for surveillance and monitoring is used in transport stations/stops or stands and terminals/hubs, parking lots, taxi ranks and the inside of transport vehicles to trigger an alarm either manually or automatically, by an 'at-risk' event. Similar monitoring systems are used at critical infrastructure, including bridges, tunnels, rail tracks, as part of a public transport security strategy. Video surveillance and monitoring can also be used for operational management e.g. for detection of public transport vehicles as they approach an intersection to provide signal priority, detect incidents and similar applications.

Electronic and mobile ticketing and payments

Electronic fare payments have become widespread in cities around the world and this has been facilitated by the proliferation of mobile devices and smartphones. Public transport operators are increasingly adopting automatic fare collection to enable more flexible ticketing, reduce administrative costs, and improve operational management and passenger travel experience.

Passenger information systems

Public transport traveller information systems have seen significant developments over the past decade as a result of the widespread use of mobile communication systems. The applications cover personal mobility apps that provide information on arrivals and departures, tracking of public transport vehicles, and journey planning. In public transport stations and at tram and bus stops, electronic displays provide information on arrival and departure times, connections, delays, incidents and other useful information to help travellers plan their trips.

Personalised public transport and mobility-as-a-service

Personalised public transport uses flexibly-routed vehicles to offer more convenient services to travellers, in some cases near door-to-door. Personalised transport includes flexible-routed operations where fixed-route buses can deviate from their main route to pick-up or drop-off passengers and random route operations that operate with variable-routing based upon the service requests received. Technologies and digitalisation are applied in journey reservations and vehicle assignment and scheduling in real-time. Ridesharing matching and reservations that rely on dynamic routing and scheduling use similar tools and are often employed by these services to calculate routes in real-time to enable ride-matching. The software requires digital maps of the road network, including lane configurations and restricted turns. The service requires in-vehicle devices to guide the driver and has links to the control centre where the ride-sharing and matching are calculated. In addition, personal mobility apps and digital online platforms also provide maps and directions on how to access public transport services as well as information on ramp access, baby changing facilities and parking spaces. This is an area that is ready for further research and investment, particularly technologies that can assist people with disabilities to provide them with better services and customer experience. Personalised public transport services build on recent trends in transport resource sharing to offer the best of the worlds of private and public transportation, i.e. convenience of door-to-door mobility similar to private vehicle and cost approaching the level of public transport. Personalised public transportation relies heavily on smartphones and an IT platform in the cloud, and is thus realising a smart form of a sharing economy. MaaS is the integration of, and access to, different transport services (such as public transport, ride-sharing, car-sharing, bike-sharing, scooter-sharing, taxi, car rental, ride-hailing and so on) in one single digital mobility offer, with active mobility and an efficient public transport system as its basis. This tailor-made service suggests the most suitable solutions are based on the user's travel needs. MaaS is available anytime and offers integrated planning, booking and payment, as well as en route information to provide easy mobility and enable life without having to own a car. MaaS digital transport service platforms (mobility platforms) that enable users to access, pay for, and get real-time information on a range of public and private (multimodal) transport options, such as public transport, ride-sharing, car-sharing, bike-sharing, scooter-sharing, taxi, car rental and ride-hailing.

Multimodal public transport

Information technology solutions, particularly multimodal travel information systems, provide travellers with information about real-time traffic flow conditions. Such conditions include average speeds or point-to-point travel times, road incidents and suggested alternative routes, scheduled road construction and special events, transit routes, schedules, fares and transfers, as well as park-and-ride facility locations and availability. With smartphones and mobile devices linked to the internet, travellers can access travel information anytime and anywhere. More advanced versions of these systems can provide users with predictive travel conditions and help with trip planning.

Public transport management

Advanced communication and information technologies are used to collect data to improve vehicle and facility operations, service planning and scheduling and personnel management. Real-time data collected from vehicle tracking and location systems is used to ensure schedule adherence and to implement corrective actions when a particular vehicle is running behind schedule. Real-time information applications can also help facilitate passengers' transfers at connecting stations. Offline, the data collected can be analysed and used to revise schedules, plan better routes, satisfy contract reporting requirements, and improve customer information systems and travel experience.

Data management and fusion

Advanced technologies and digitalisation enable more extensive, up-to-date, and accurate real-time information from different sources, linking these data using standardised and optimised interfaces for data fusion and interpretation. The data management and fusion systems can be used to provide access to updated information about timetable disruptions, route changes and other applications. Advanced communications such as 5G, combined with cloud infrastructure and fast learning algorithms also offer attractive solutions to handle large volumes of data.

Freight, logistics and supply chain management

In this research, the freight, logistics and supply chain sector is classified into the following key functional areas.

Warehousing and contract logistics

A key function in freight logistics is efficient warehousing and contract logistics. Warehousing provides primary functions such as accumulation, sortation, allocation, and assortment of inventory, but also value-adding functions such as packaging, assembly and postponement. This is an area where technologies such as IoT, information systems and emerging blockchain applications can have a major role in enabling smart warehouses, which can help to boost efficiency and speed throughout the supply chain. In recent years, Autonomous Mobile Robots (AMR) technologies have become popular among large warehousing operators, particularly those with e-commerce operations. Such robots provide faster and more efficient picking operations, allowing for quicker delivery to customers.

Last kilometre delivery and urban freight

Last kilometre delivery includes the activities that involve the final segment of goods delivery to the doorstep of customers. Last kilometre delivery is known as the most expensive and polluting segment of the value chain. This is an area that is ripe for technology solutions, particularly innovations that can help reduce costs and improve efficiencies while also reducing emissions and negative impacts on urban transport. For example, IoT solutions can help in improving the performance of urban freight collection and delivery fleets through tracking of vehicles and consignments allowing for demand-responsive operations where the fleets can be redeployed and routed/re-routed in real-time. A range of existing and emerging technologies are used to optimise route and scheduling systems, just-in-time deliveries, onboard real-time vehicle monitoring, automatic vehicle location (AVL), computer-aided dispatch and electronic payments. More recently, platform-based technologies and crowdsourcing mechanisms have received additional momentum in this space to utilise the dormant resources for delivery and storage of goods.

Trade facilitation and documentation

Trade facilitation enables faster, safer and more secure freight across borders (imports and exports). Technologies can have a major role in trade facilitation by focusing on simplification and harmonisation of trade procedures and related information and documentation related to exchange between the various partners in the supply chain. Digital technologies can also be used for electronic processing of trade documents and related data exchanges. Embedded IoT sensors (e.g. low-cost radio frequency identification or RFID) linked with data analytics can help to integrate complex inventories into cloud-based platforms. Blockchain technology can also be used to enable deeply encrypted, immutable records in a high-security distributed ledger and help build trust between logistic providers and collaborators.

Freight forwarding, aggregation and customs brokerage

International shipments involve several parties, operators, and jurisdictions. Freight forwarders are responsible, on behalf of the shippers, for coordination of activities involved in the shipment of cargo from origin to destination via a single or multiple transport modes. The freight forwarding role is essential for the safe and cost-efficient transport and storage of cargo across national and international borders. Freight forwarders act as intermediary players between different types of carriers and customers to negotiate the best price and value. Freight forwarders also act as logistics aggregators to optimise the existing capacity through appropriate consolidation mechanisms. While freight forwarding is associated with the physical movement of cargo, customs brokerage is related to handling required paperwork for import and export of goods. Technologies and digitalisation applications include routing and scheduling systems, just-in-time delivery, AVL, onboard monitoring and electronic payments. ITS and technology applications can improve freight forwarding and aggregation through better planning, loading and efficient route planning. Real-time onboard monitoring technologies and telematics can also help in avoiding or reducing the impact of disruptions.

Asset and cargo management

This includes technologies and digitalisation applications, such as telematics for tracking and diagnostics, fuel management, health and safety management and dynamic scheduling. This area is characterised by the use of advanced data and video analytics solutions that rely on the mining, collection, and inferences drawn from large stockpiles of information from ships, ports and vehicles in real-time as well as historical data. Software applications for vehicle routing planning are also becoming common for small and large fleet operators to better optimise their resources and improve service delivery. Computerised vehicle routing and scheduling software are used to reduce vehicle travel time and driver stress, resulting in better vehicle fleet and resource utilisation while reducing travel distances and fuel costs. Furthermore, vehicle location tracking technologies can be used to estimate arrival times and reduce waiting times in the loading and unloading of cargo. Other examples include the use of RFID tags that enable tracking individual containers or contents across all modes used in transporting goods from the factory to the final delivery/destination point. Technologies help to improve efficiency through better knowledge and detailed understanding of stock movements, and departure and arrival time estimates. Global positioning system (GPS) and satellite-enabled tracking devices can also be used to enable active location data transmission and provide continuous end-to-end load tracking. Some of the emerging solutions also include augmented reality (AR) technology that adds immense value to container and cargo management by optimising cargo planning, maintenance, inspection and navigation. Cloud technologies can also be used as enablers for a range of solutions, including IoT for data collection and processing to identify the location and condition of a container, assess possible bottlenecks along the container's route, and ensure effective port processes and operations.

Other applications in this area include the use of technology to improve transparency of supply chain processes and shipments, and reduce handover, waiting and handling times. These types of control and management solutions are enabled through cloud-based technologies, including access to data from the extended supply chain and real-time status updates across the entire value chain. It also includes RFID and GPS tracking, real-time visibility of container movements, and integration of sensors for remote temperature or humidity monitoring (cold chain) in the supply chain management and control processes. In recent years, technologies such as Electronic Data Interchange (EDI) and cloud-based services have allowed for more efficient exchange of information among parties, resulting in enhanced customs brokerage and border crossing processes.

Technology-based services for e-commerce support

These are vital functional areas that support procurement and delivery of products and services purchased via the internet. This includes commerce-enabled apps and websites that provide search capabilities and automated payment systems. Freight transport operators can use advanced technologies to provide easy-to-use interfaces that allow users to determine the most appropriate service based on cost, customer feedback and other criteria. This functional area is supported by warehousing, transportation, and contract logistics services.

Rail transport functional areas

The rail transport sector is classified into the following key functional areas. A number of other functional areas related to rail public transport and rail freight are covered elsewhere in this framework and can be found under the public transport and freight sector sections.

Information and communication technology services

Information and communication services and information network platforms in rail transport include train operation control by using real-time information on passenger loads and railway disruptions and incidents that might affect network capacity. This helps to reduce train schedule disruptions by enabling more responsive train operations and controls that are adaptive to demand and infrastructure conditions. Increasingly, train operators are investing more in high capacity ground-to-train telecommunications that can facilitate deployment of systems and technologies for safer and more advanced train network control systems. Technologies and digitalisation are also increasingly being used in a wide range of railway services and solutions. These include design and development, signalling and communication engineering, video and image analytics, predictive maintenance, intelligent automation, and testing and validation. These tailor-made offerings help global railway manufacturers to enhance operational efficiencies, increase reliability, and improve safety.

Asset condition monitoring

This includes implementing massive IoT systems across the whole rail network to enable train control through linking devices inside locomotives, trackside sensors, and back-office computer systems. These technologies also help in monitoring track movements and conditions, facilitating predictive maintenance where and when needed.

Operations and track signalling

Below-rail operations and rail signalling use digital systems to enhance the reliability, performance and cost-effectiveness of operations. Advanced technologies enable railway operators to shift from ‘fixed-block’ to ‘moving-block’ signalling systems through virtual coupling with real-time information and train-to-train communication technologies. From an infrastructure investment consideration, this can help operators eliminate the need for continued investment in outdated railway signal boxes and heavy copper wires. These investments can be substituted for more cost-effective advanced train management and control systems, including provision of real-time information to the train driver using in-cabin displays.

Aviation and air transport functional areas

In this research, the aviation sector is classified into the following key functional areas.

Airport safety and security

Security remains a high priority for all airports. This area continues to receive significant investment in video infrastructure and AI based video analytics, enhanced biometric recognition systems, unusual behaviour detection, profiling, unattended-baggage management, as well as monitoring and controlling building and fencing access. Digitalisation and automation also help to improve data quality and security and make it easier to share valuable data among consumers with more confidence about privacy protection. Advanced information systems, operations and control systems, including blockchain are also being considered for cybersecurity and data protection. In addition, video monitoring and checkpoint scanning systems and associated technologies, such as computed tomography technology help to enhance threat detection capabilities, especially for carry-on baggage. These technologies offer airports innovative solutions, particularly given the large number of passengers that need to be cleared during very short durations. This helps in ensuring passenger and staff safety without the need to devote valuable airport real estate to more security lanes.

Airport operations

Advanced technology applications and digitalisation in airport operations include resource management systems that leverage IoT to provide more comprehensive solutions, including aircraft estimated time of arrivals and estimated time of departures. Operational efficiencies can also be increased in a number of ways such as by leveraging collaborative and web-services platforms that can be used to improve financial services and streamline accounts payable and receivable processes. Other systems that can help improve operational efficiencies include intelligent building management platforms to reduce electricity and gas usage, and reduce utility bills. In addition, automation of passenger services, including faster check-in and passport clearance can help reduce travel stress and improve travel experience. Customer-focused mobile applications, coupled with big data and customer relationship management (CRM) systems can help airport staff to provide personalised e-services to passengers. These services can include real-time and up-to-date information about customers' upcoming trips, which helps them prepare in advance and enhance their airport experience and utilisation of airport services. Other services enabled by mobile platforms include retrieval of trip itineraries, and easy access to passenger boarding passes and other travel-related information.

Capacity management

Advanced technologies and information systems also help to provide deeper understanding and monitoring of passenger flows, which can help in optimising the use of airport infrastructure and retail services. This can also facilitate predictive maintenance that reduces breakdowns and maintenance costs and maximises airport asset utilisation and customer satisfaction.

Maritime and shipping functional areas

In this research, the maritime sector is classified into the following key functional areas.

Safety and security

In-sea and coastal safety and coordination with ports and pilots is essential for efficient maritime transport. Automatic identification and real-time monitoring systems help to avoid and mitigate the risk of accidents. E-navigation technologies such as Automatic Identification System (AIS), Integrated Bridge System, Vessel Traffic Services and locator beacons allow for harmonised collection, analysis and sharing of marine-related data on board of vessel and on-shore for enhanced navigation of vessels in national and international waters. These technology-driven solutions allow for vessels to be remotely monitored and managed, with human supervision.

Port operations

This includes technologies for improving port operations, port services coordination, yard planning and port automation to optimise berth usage, reduce the number of moves in container handling, maximise yard and equipment usage, and better control both landside and waterside processes. Technology-driven port operations are enabled through IoT/sensor networks, smart buoys for collection of tidal data, temperature, and pollution levels, automated stacking using ship-to-shore container cranes, and air and underwater drones for inspection.

Administrative procedures

Advanced technologies, software and digitalisation solutions are used in maritime administrative procedures for faster booking, paperless documentation, and coordination of administration procedures among various parties in management and handling of cargo. Examples of technologies used include predictive analytics to forecast demand cycles, booking allocation management, vessel deployment, rate analytics and instant freight quotes, online booking, and blockchain for smart contracts, insurance and financial transactions. This also include paperless customs administration and software for customs load identification.

Ocean and short-sea shipping

Short-sea shipping is a functional area related to the maritime transport of goods and passengers over relatively short distances, compared to long distance ocean shipping that expands across international waters. In contrast to ocean shipping that involves international shipping companies operating large vessels, short-sea shipping generally involves local players operating smaller vessels in a region or coastal area. Short-sea shipping mainly covers the operations and management of vessels operating between predetermined ports, but also the supporting services that expand across the port and its hinterland. For example, digital freight marketplaces allow for enhanced planning and scheduling of cargo handling and optimised vessel capacity in markets with lower and unstable demand. The use of autonomous and semi-autonomous technologies is also becoming prevalent in short-sea shipping to improve safety of vessels and passengers.

Ocean shipping involves the maritime transport of cargo across international waters. Advanced technologies and digitalisation in the ocean shipping sector include GPS and satellite technologies used in automatic identification systems that rely on communication, remote sensing for optimal paths, e-navigation, and monitoring of weather conditions. Digital route management of ships (real-time route management) can also be used to improve journey duration and efficiency. Intelligent technologies are also used in ship propulsion systems to provide greater control and enable speed control to high tolerance values. Another technology used for ocean shipping is integrated control systems, which enable monitoring entire vessels and operating systems and components that make up massive vessels.

Maritime traffic management

This functional area includes applications of advanced technologies for central management and coordination of vessel traffic, port and terminal operations as well as performing coastal surveillance. Such technologies include automatic identification systems on board ships and vessels supported by a range of IoT devices. Advanced solutions provide remote control to the vessel's vital information systems, operators and passengers that would have otherwise required physical presence. Integrating smart technology such as AI and ML into these systems can also enable vessels to stay on course without requiring constant input from the vessel's captain. These actions minimise the chances of human error and also allow real-time route information to be implemented with relative ease.

Common functional areas across multiple sectors

A number of sectors include common functional areas, particularly those related to air, maritime, rail and freight services.

Terminal operations and management

Advanced technologies and digital solutions can play an important role in terminal operations for intermodal freight. These can also provide benefits in improving efficiency of operations and increasing throughput of cargo terminals, as well as better tracking of different loads throughout the intermodal transport chain. Through IoT applications, end-to-end asset tracking and e-manifests (such as systems for tracking hazardous waste shipments electronically) enable loads to be identified, tracked and processed more quickly than manual systems. Information about the order in which containers enter the terminal can be transmitted in advance to facilitate cargo handling plans that improve efficiency. Digitalisation can also facilitate efficient movement of containers or loads from inbound arrival to outbound departure points without the current long layovers required for checking and verification. In maritime operations, technologies and information systems are used to manage vessels passing through a port to improve efficiency and optimise terminal utilisation. AI, ML and big data for smart vessel operations, digital cargo and bay arrangement optimisations are some examples of technologies and digitalisation applications used in terminal management and intramodality. Advanced technologies that enable end-to-end asset tracking throughout the intermodal transport chain are also gaining widespread acceptance as cost-effective solutions for enhancing operations.

Quarantine and inspection

This functional area also includes digital solutions and technologies for quarantine inspection and compliance. This area has seen considerable investment in technologies in recent years to help authorities with quarantine, as well as inspection and compliance with legislative obligations through enhanced detection, monitoring and information sharing by enforcement agencies.

Infrastructure services and predictive asset maintenance

Technologies and digitalisation have enabled many advances in transport infrastructure services. Geographic Information Systems platforms and 3D modelling capabilities can aid engineers in optimising space and surfaces. In airports, for example, they can include proper design of passageways to baggage claim areas and ticketing counters. Virtual reality (VR) and 3D modelling can also be used in surveys and field inspections. During construction and infrastructure expansion projects, automated communication and real-time data on project performance provide more precise and up-to-date information for engineers on site to help them track millions of vital construction components. Engineering services and asset management is also an area that is receiving considerable attention in terms of automation and digitalisation. For example, maintenance and engineering services can use IoT (including sensors for self-diagnosis and reporting) for predictive maintenance and remote support of assets, which reduces downtime and costs. AI and ML technologies can also shift operations from time-based to condition-based maintenance for better asset management and smart maintenance of infrastructure, railway tracks, catenary, bridges, tunnels, signalling and other electric facilities. Importantly, advanced technologies and digital applications in predictive maintenance will see an increasing focus on AI developments and applications of blockchain and IoT to monitor and predict critical equipment, and reduce asset maintenance costs.

Active transport functional areas (emerging)

Digitalisation of the active transport sector is an emerging area that is witnessing substantial growth. A number of key functional areas have been identified based on case studies. The sector is included in the analysis as it is expected to experience more transformation and growth in the short term and will benefit from digitisation and innovations including IoT, automation, AI, blockchain and other emerging technology solutions. In this research, the active transport sector is classified into the following key functional areas.

Safety of riders and other vulnerable road users

Applications of digitalisation and advanced technologies in the safety of active transport users include active or passive (user-activated) traffic signal prioritisation based on cyclist detection and bicycle turn-by-turn navigation system for cyclists. They also include intelligent cycling infrastructure that reflects cycle flow patterns within a defined area such as major destinations, including schools and train stations. There is also a range of new developments in smart helmets and wearable devices, as well as communications between users and infrastructure assets, although these are still nascent technologies at this stage.

In order to provide safe road infrastructure that integrates protection for vulnerable road users, advanced technologies are used for better design and maintenance of road infrastructure to reduce accident risk, manage conflicts at critical locations and reduce the impact of collisions with vulnerable road users. This is a growing area of research and applications, particularly due to the increased use of active transport modes during the pandemic.

Parking management

Digitalisation and advanced technologies are used to manage the allocation of parking spaces for active transport modes. Better parking management helps improve the travel experience of users by providing real-time information on spaces. Technology-based parking information systems are integrated with network-wide traffic management and control to minimise bicycle parking search times and optimise traffic management overall. In recent times, with the proliferation of dockless e-bikes and e-scooters, parking management has become more important to avoid littering of sidewalks. Sensors and technologies embedded in these micro-mobility devices can help to minimise inappropriate device parking practices.

Fleet management

For companies that operate shared bikes and scooters, integrated advanced technologies are used in fleet management, depot management, asset tracking, safety and enhanced user experience. Using app-based tools, operators can capture and release vehicles, track and monitor vehicle status, conduct in-field repairs and routine maintenance, and optimise fleet sizes in response to changing demands.

Travel experience

Cyclists, pedestrians and micro-mobility users also benefit from advanced technologies that include the use of crowdsourced digital maps and apps that identify obstructive road features for users. Device-mounted sensors and in-vehicle detection systems are also used for blind spot monitoring and for enabling cooperative communications systems using RFID tags fitted on bicycles and micro-mobility devices.

Bibliometric analysis

Bibliometric analysis

This section presents a brief bibliometric analysis of the literature that addresses digitisation in transport and freight. This analysis will help inform the next stages and selection of case studies and identification of suitable metrics for evaluations (**Table 3**). More bibliometric details are provided in **Appendix A**, including the inclusion and exclusion criteria used to identify the contributing articles.

For each sector identified, the following bibliometrics were examined:

- chronological publication trends
- publications per country
- publications per organisation
- keywords analysis

Summaries for each sector are provided below.

Rail

There were 4,829 articles that covered track signalling, high-speed train, traction, traffic control, rolling stock, locomotives, traffic signalling, cargo tracking, terminal management, rail timetabling, asset tracking, e-manifest, rail maintenance and rail terminal operations. The volume of publications increased over the years – from 412 publications in 2010 to 587 publications in 2020, and 290 in the first half of 2021. Most of the publications were conference papers (51%) and journal articles (44%). The countries that published the most included China, US, UK, Italy and Japan (Australia was ranked #14). The countries with the highest citations included China, US, UK, Italy, Germany (Australia was ranked #10). The organisations that published the most included Beijing Jiaotong University (China), Southwest Jiaotong University (China), China Academy of Railway Sciences (China), Central South University (China), Korea Railroad Research Institute (South Korea). Australia was ranked #46 with Central Queensland University topping the list of Australian universities. The most used keywords (2019-21) were adaptive control, deep learning, 5G, energy efficiency, multi-object optimisation, traction system, communication train control and high-speed train.

Road sector

There were 3,532 articles that covered road safety, congestion management, adaptive traffic signals/control, travel information systems, network management/control and managed motorways. The volume of publications has increased substantially – from 171 publications in 2010 to 524 publications in 2020, and 301 in the first half of 2021. Most of the publications were conference papers (53%) and journal articles (40%). The countries that published the most included China, India, US, France and Germany (Australia was ranked #9). The countries with the highest citations included US, China, UK, Canada and Italy (Australia was ranked #7). The organisations that published the most included University of Waterloo (Canada), CNRS Centre National de la Recherche Scientifique (France), Tsinghua University (China), Ministry of Education (China), and Beijing University of Posts and Telecommunications (China). Australia was ranked #9 with Queensland University of Technology topping the list of Australian universities. The most used keywords (2019-21) were deep learning, automated vehicles, IoT, 5G and edge computing.

Table 3: Summary bibliometric analysis of Scopus literature

Rail	Track signalling, high-speed train, traction, traffic control, rolling stock, locomotives, traffic signalling, cargo tracking, terminal management, rail timetabling, asset tracking, e-manifest, rail maintenance and rail terminal operations	4,829	China, US, UK, Italy, Japan and Australia was ranked (#14)	Beijing Jiaotong University (China), Southwest Jiaotong University (China), China Academy of Railway Sciences (China), Central South University (China), Korea Railroad Research Institute (South Korea) and Australia was ranked (#46) with CQ University	Adaptive control, deep learning, ML, 5G, energy efficiency, multi-object optimisation, traction system, communication train control and high-speed train.
Road transport	Road safety, congestion management, adaptive traffic signals/control, Travel Information Systems, Network Management/Control and Managed Motorways	3,532	China, India, US, France and Germany and Australia was ranked (#9)	University of Waterloo (Canada), CNRS Centre National de la Recherche Scientifique (France), Tsinghua University (China), Ministry of Education (China), Beijing University of Posts and Telecommunications (China), and Australia was ranked (#9) with Queensland University of Technology	Deep learning, automated vehicles, IoT, 5G and edge computing.
Active Transport	Safety, Fleet Management, Parking, Travel experience, Rider Services, Predictive maintenance and Infrastructure service	3,122	China, US, Germany, Japan, UK and Australia was ranked (#11).	Chinese Academy of Sciences (China), Tsinghua University (China), Ministry of Education (China), Beijing Institute of Technology (China), The University of British Columbia (Canada) and Australia was ranked (#40) with Monash University.	Deep learning, battery safety, e-scooters, pedestrian safety, EVs and optimisations
Freight	Asset tracking, cargo tracking, last kilometre delivery, Trade facility Documentation, Freight forwarding, Warehousing, Contract logistics, e-commerce, Fleet management and optimisations, Urban freight, Routing and scheduling, Reverse and green logistics services, Truck rolling, Truck Monitoring, Truck Safety, Truck Park, Terminal process and Intermodal	2,793	China, US, Germany, India, Italy and Australia was ranked (#12)	Wuhan University of Technology (China), Dalian Maritime University (China), Norges teknisk-naturvitenskapelige universitet (Norway), Akademia Morska w Gdyni (Poland), Harbin Engineering University (China) and Australia was ranked (#41) with University of Tasmania.	Blockchain, smart warehouse, drones, Logistics 4.0, ML, path planning and last kilometre delivery.
Maritime	Short-Sea Shipping, Cargo and Container Management, Maritime Traffic Management, Terminal management and intramodality, Ocean Shipping, Crew management and workforce development, Port Operations, Supply Chain Control, Administrative Procedures, Environmental Regulations and Safety	2,387	included China, US, UK, Norway, Germany and Australia was ranked (#13)	Wuhan University of Technology (China), Dalian Maritime University (China), Norges teknisk-naturvitenskapelige universitet (Norway), Akademia Morska w Gdyni (Poland), Harbin Engineering University (China) and Australia was ranked (#41) with University of Tasmania.	Autonomous ships, deep learning, ML, collision risk, risk assessment and data mining,
Public Transport	Video Surveillance Monitoring, Management, Electronic and Mobile Ticketing, Driver and Vehicle Safety, Accessibility, Public Transport Scheduling, Traveller Information Systems, Data Management, Rail Traffic Management, Passenger Safety, Enforcement, Security, Multi-modal public transport.	2,109	US, China, Italy, UK, Germany and Australia was ranked (#6)	Delft University of Technology (Netherlands), Southeast University (China), University College London (UK), Ministry of Education (China) and Università degli Studi di Napoli Federico II, (Italy) and Australia was ranked (#6) with RMIT University	Shared mobility, autonomous vehicles, travel behaviour, deep learning and service equality.
Aviation and air transport	Airport Operations, Airport Safety, Airport Security, Airport Capacity Management, Accessibility, Passenger Services, Predictive maintenance, Passenger/ Staff Safety, Infrastructure services and Airport Parking.	1,000	US, China, India, Germany, UK and Australia was ranked (#10).	Deutsches Zentrum fur Luft- Und Raumfahrt (Germany), Nanjing University of Aeronautics and Astronautics (China), NASA Ames Research Centre (US), University of Southern California (US), Politechnika Warszawska (Polandand) and Australia was ranked (#41) with RMIT University	Deep learning, AI, airport management, IoT, image processing, computer vision and anomaly detection.

Active transport

There were 3,122 articles that covered safety, fleet management, parking, travel experience, rider services, predictive maintenance and Infrastructure service. The volume of publications has increased substantially – from 92 publications in 2010 to 560 publications in 2020, and 392 in the first half of 2021. Most of the publications were journal articles (46%) and conference papers (42%).The countries that published the most included China, US, Germany, Japan and the UK (Australia was ranked #11). The countries with the highest citations included US, China, Canada, Germany and South Korea (Australia was ranked #8). The organisations that published the most included Chinese Academy of Sciences (China), Tsinghua University (China), Ministry of Education (China), Beijing Institute of Technology (China), The University of British Columbia (Canada). Australia was ranked #40 with Monash University topping the list of Australian universities. The most used keyword in recent years (2019-21) were: deep learning, battery safety, e-scooters, pedestrian safety, EVs and optimisations.

Freight

There were 2,793 articles that covered asset tracking, cargo tracking, last kiloemtre delivery, trade facility documentation, freight forwarding, warehousing, contract logistics, e-commerce, fleet management and optimisation, urban freight, routing and scheduling, reverse and green logistics services, truck rolling, truck monitoring, truck safety, truck parking, terminal processes and intermodal freight. The volume of publications has fluctuated over the years – from 176 publications in 2010 to 428 publications in 2020, and 282 in the first half of 2021. Most of the publications were conference papers (48%) and Journal articles (40%). The countries that published the most included China, US, Germany, India, Italy (Australia was ranked #12). The top countries that have the highest citations included US, China, Italy, India, UK (Australia was ranked #8). The organisations that published the most included Wuhan University of Technology (China), Dalian Maritime University (China), Norges teknisk-naturvitenskapelige universitet (Norway), Akademia Morska w Gdyni (Poland), Harbin Engineering University (China). Australia was ranked #41 with University of Tasmania topping the list of Australian universities. The most used keywords (2019-21) were blockchain, smart warehouse, drones, logistics 4.0, ML, path planning and last kilometre delivery.

Maritime

There were 2,387 articles that covered short-sea shipping, cargo and container management, maritime traffic management, terminal management and intramodality, ocean shipping, crew management and workforce development, port operations, supply chain control, administrative procedures, environmental regulations and safety. The volume of publications increased over the years – from 119 publications in 2010 to 400 publications in 2020, and 186 in the first half of 2021. Most of the publications were conference papers (54%) and journal articles (36%). The countries that published the most included China, US, UK, Norway and Germany (Australia was ranked #13). The countries with the highest citations included China, US, UK, Norway and Netherlands (Australia was ranked #14). The organisations that published the most included Wuhan University of Technology (China), Dalian Maritime University (China), Norges teknisk-naturvitenskapelige universitet (Norway), Akademia Morska w Gdyni (Poland), Harbin Engineering University (China). Australia was ranked #41 with University of Tasmania topping the list of Australian universities. The most used keywords (2019-21) were autonomous ships, deep learning, collision risk, risk assessment and data mining.

Public transport

There were 2,109 articles that covered video surveillance monitoring, management, electronic and mobile ticketing, driver and vehicle safety, accessibility, public transport scheduling, traveller information systems, data management, rail traffic management, passenger safety, enforcement, security, and multimodal public transport. The volume of publications has increased over the years – from 99 publications in 2010 to 343 publications in 2020, and 223 in the first half of 2021. Most of the publications were journal articles (52%) and conference papers (41%). The countries that published the most included US, China, Italy, UK and Germany (Australia was ranked #6). The countries with the highest citations included US, China, UK, Australia and Italy. The organisations that published the most included Delft University of Technology (Netherlands), Southeast University (China), University College London (UK), Ministry of Education (China) and Università degli Studi di Napoli Federico II, (Italy). Australia was ranked #6 with RMIT University topping the list of universities in Australia. The most used keywords (2019-21) were shared mobility, autonomous vehicles, travel behaviour, deep learning and service equality.

Aviation

There were 1,000 articles that covered airport operations, airport safety, airport security, airport capacity management, accessibility, passenger services, predictive maintenance, passenger/staff safety, infrastructure services and airport parking. The volume of publications has fluctuated over the years – from 67 publications in 2010 to 128 publications in 2020, and 68 in the first half of 2021. Most of the publications were conference papers (65%) and journal articles (27%). The countries that published the most included US, China, India, Germany and the UK (Australia was ranked #10). The countries with the highest citations included US, China, UK, Germany and Italy (Australia was ranked #7). The organisations that published the most included Deutsches Zentrum fur Luft- Und Raumfahrt (Germany), Nanjing University of Aeronautics and Astronautics (China), NASA Ames Research Center (US), University of Southern California (US), Politechnika Warszawska (Poland). Australia was ranked #41 with RMIT University topping the list of Australian universities. The most used keywords (2019-21) were deep learning, AI, airport management, Internet of Things, image processing, computer vision and anomaly detection.

The full bibliometric results, including the search criteria used for inclusion and exclusion of articles, are presented in **Appendix A**.

Emerging technologies

Emerging technologies

This study also identified key emerging technologies that offer promise in addressing the key challenges facing the transport and freight sectors, and have potential to improve efficiency and operations.

In this section of the report, ‘emerging technologies’ and ‘disruptive technologies’ are referred to interchangeably and refer to important technologies from any scientific discipline that share four key ‘disruptive’ characteristics. These characteristics are:

- high rate of technology change
- broad potential scope of impact
- large economic value that could be affected
- substantial potential for disruptive economic impact.

Although many technologies have the potential to meet these criteria eventually, we focus on technologies with potential impact that is near enough at hand to be meaningfully anticipated and prepared for. Therefore, the focus in this section will be on technologies that are believed to have significant potential to drive economic impact and disruption over the next decade.

The first characteristic of a disruptive technology is that it is rapidly advancing or experiencing breakthroughs. Disruptive technologies typically demonstrate a rapid rate of change in capabilities in terms of price and performance relative to substitutes and alternative approaches, or they experience breakthroughs that drive accelerated rates of change or capability improvements.

The second characteristic is that the potential scope of impact is broad. To be economically disruptive, a technology must have broad reach, touching companies and industries and affecting (or giving rise to) a wide range of products or services. The mobile internet, for example, could affect how billions of people go about their lives, giving them tools to become potential innovators or entrepreneurs, making the mobile internet one of the most impactful technologies that we will discuss later. Similarly, IoT technology could connect and embed intelligence in billions of objects and devices all around the world, affecting the mobility, health, safety, and productivity of billions of people.

The third characteristic of a disruptive technology is that significant economic value could be affected. An economically disruptive technology must have the potential to create a massive economic impact. The value at stake must be large in terms of profit pools that might be disrupted, additions to GDP that might result, and capital investments that might be rendered obsolete. Advanced robotics, for example, similar to what is expected in autonomous vehicles, has the potential to affect US$6.3 trillion in labour costs globally. Cloud technology has the potential to improve productivity across US$3 trillion in global enterprise information technology spending, as well as enabling the creation of new online products and services for billions of consumers and millions of businesses alike (Dia, 2021).

The fourth characteristic of a disruptive technology is that the economic impact is potentially disruptive. Technologies that matter have the potential to dramatically change the status quo. They can transform how people travel, live and work and create new opportunities or shift surplus for businesses, and drive growth or change the comparative advantage for countries. Energy storage technologies, for example, could change how, where, and when we use energy for transport.

A number of studies in the literature have over the past few years analysed a large number economically disruptive technologies in the transport sector. More than 50 possible candidate solutions were considered and reviewed from academic journals, the business and technology press, analysis of published venture capital portfolios, and hundreds of interviews with relevant experts and thought leaders. In these studies, each candidate technology was assessed according to the four criteria, eliminating some that were too narrow and others that seem unlikely to start having significant economic impact over the next decade. The technologies presented in this section have potential to affect billions of consumers, hundreds of millions of workers, and trillions of dollars of economic activity across industries. Today, there are at least seven forces of established and emerging trends that are expected to have a profound impact on urban mobility over the next two decades **(Figure 5)**.

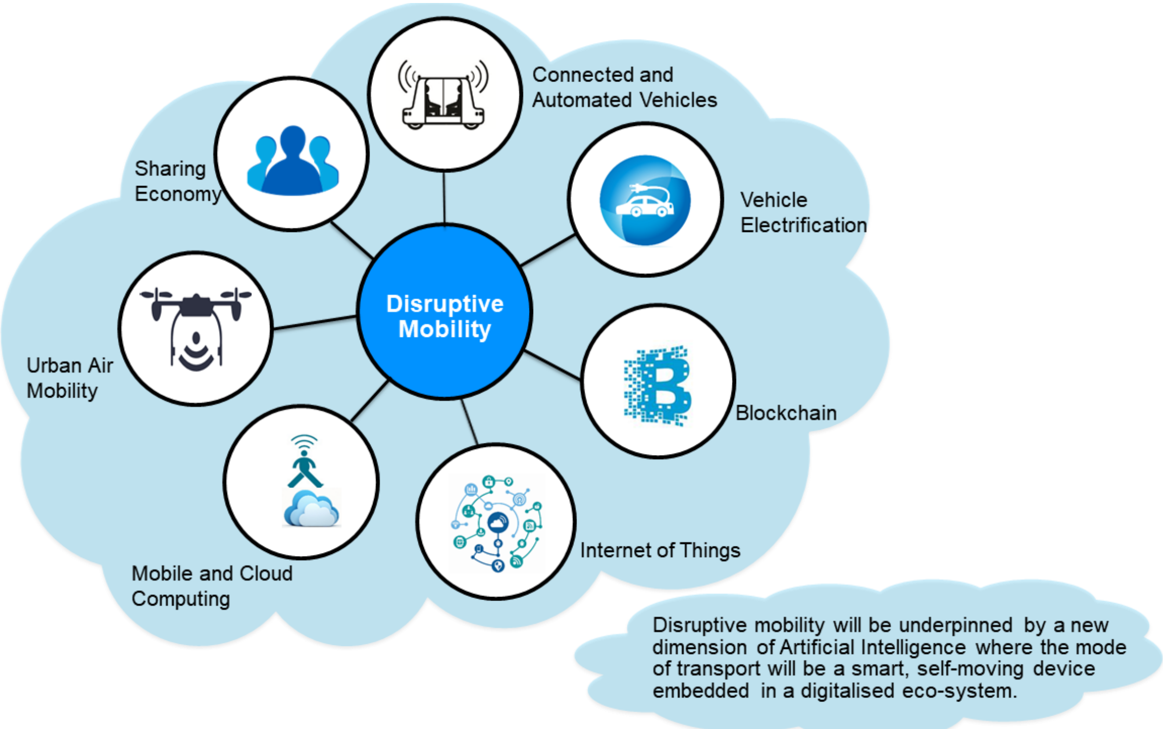

Figure 5: Disruptive mobility underpinned by AI solutions
Source: Authors

Technologies such as CAVs, the sharing economy, cloud and fog computing, and blockchain are each quite significant on their own (Dia, 2017). But the real disruption will occur when these technologies converge and come together. Then, their disruptive forces will magnify to create additional values and provide innovations (Dia, 2017).

Connected and automated vehicle technologies

Connected and automated vehicles comprise a range of sensors, radars, cameras and advanced software algorithms that allow the vehicle to assist the driver in the driving task. In cases of high automation, these vehicles also reduce reliance on human drivers and can perform many of the essential driving functions depending on the level of automation (Dia, 2017; Jermakian, 2011; ITF, 2015; Nvidia, 2016; Baker et al., 2016; Burt et al., 2014)

Levels of vehicle automation

Five levels of driving automation are now widely recognised in the industry (SAE International, 2018; ITF, 2015; CrowdCompanies, 2016). These are shown in **Figure 6** which identifies how the driving task is divided between human and machine (Dia, 2017).

Automation Level	Name	Description
0	No automation	The human driver performs all aspects of the dynamic driving task, even when enhanced by warning or intervention systems.
1	Driver assistance	A driver assistance system executes specific tasks such as steering <u>or</u> acceleration-deceleration using information about the driving environment, with the expectation that the human driver performs all remaining aspects of the dynamic driving task.
2	Partial automation	One or more driver assistance systems executes specific tasks such as <u>both</u> steering <u>and</u> acceleration-deceleration using information about the driving environment, with the expectation that the human driver performs all remaining aspects of the dynamic driving task.
3	Conditional automation	An automated driving system performs all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene.
4	High automation	An automated driving system performs all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene.
5	Full automation	An automated driving system performs all aspects of the dynamic driving task under all roadway and environment conditions that can be managed by a human driver.

Figure 6: The five levels of vehicle automation urban mobility solutions
Source: Authors. Adapted from SAE International (2018)

For example, Level 0 does not include any automation (driving is performed entirely by a human driver) while Level 5 is considered full automation (driving is entirely performed by an automated driving system) (Dia, 2017). Efforts towards full automation will involve gradual improvement of automated driving systems available in conventional vehicles so that drivers can shift more of the dynamic driving task to these systems (ITF, 2015). It will then evolve into deploying vehicles without a driver and gradually expanding this operation to more contexts. Many of today's mass market vehicles are capable of driver assistance (Level 1) and some also include an active lane-keeping assist feature in a way that makes them capable of partial automation (Level 2). Levels of automation beyond conditional automation (such as Level 3) may operate on the basis of inputs solely from vehicle sensors or from a combination of vehicle and infrastructure information (ITF, 2015). High automation (Level 4) describes a driving system that can always revert to a minimal risk condition in the case of a human driver not resuming driving (ITF, 2015). For this reason, a highly automated driving system is capable of operating in some, but not necessarily all, contexts or driving modes. The highest level of automation (Level 5), currently referred to as fully autonomous vehicles, would operate without a driver. Full automation is difficult and challenging because it requires solving problems that are not just technological. A fully automated vehicle needs to handle all situations, including its own equipment failure. To sense the environment, autonomous vehicles use a combination of sensors, including LiDAR (Light Detection and Ranging), radar, cameras, ultrasonic, and infrared (Dia, 2017), which complement one another.

Self-driving algorithms – the key differentiator

Automated vehicles include advanced algorithms to process sensor data and control the vehicle. To allow full autonomous operation without a backup driver, the technology must be sufficiently robust so that even with failures, the vehicle can manoeuvre to a safe stop (Dia, 2017). Developing this level of reliability is challenging and most promising developments to date have been in the development of AI solutions for self-driving systems. In these solutions, a deep neural network is trained on millions of examples of images from the urban environment (Dia, 2017). It is expected that self-driving algorithms will be a key differentiator in the performance of autonomous vehicles with the majority of vehicle manufacturers investing heavily today in their development and testing.

The promise of automated vehicles – the moral imperative

Self-driving vehicles have captured people's imaginations over the past few years and have also inspired some visions of a different future (Dia, 2017). One aspect that most specialists agree on is that self-driving vehicles can have a positive impact on-road safety. As was discussed before in the global transport challenges section, nearly 1.2 million people die in road traffic crashes worldwide every year. Around 70-90% of these crashes are caused by human error. The promise of autonomous vehicles is that when they are fully developed, they will remove or reduce reliance on human drivers which would result in a substantial reduction in crashes and fatalities (Anderson et al, 2014; Dia, 2017; Bagloee et al., 2016b; Duarte and Ratti, 2018). There are still many challenges that need to be overcome before autonomous vehicles are ready for deployment. In the meantime, many of the component technologies are already being introduced in new vehicles which will help improve their safety.

Vehicle electrification

Vehicle electrification will be a major component of the future transport ecosystem particularly around digitalisation and connectivity, on-board control systems, smart charging and EVs as energy suppliers (peer-to-peer digital platforms). They will also play a major role in addressing the global urban mobility challenges. The on-going momentum about their adoption suggests that around 20-30% of all vehicles sold will be electrified by 2030. This uptake will likely be facilitated through changing consumer attitudes and acceptance of vehicle electrification, wider rollout of charging infrastructure, and a global shift in regulations and policies that will favour low carbon and low emissions modes of transport Dia (2019).

Changing consumer attitudes

Results from recent global surveys found 30-45% of vehicle buyers would consider an EV (Dia, 2019). The survey showed consumer demand is starting to shift in favour of EVs. Consumers, however, were generally concerned about driving range and high costs for battery packs. Surveys of Victorian consumers in Australia showed they would be interested in EVs if governments provided more incentives (Dia, 2019). A survey by the Royal Automobile Club of Victoria, conducted in 2017, found around 50% of participants would consider owning an EV (Dia, 2019).

Broader access to charging infrastructure

According to the same global surveys, consumers found access to charging infrastructure to be the third largest barrier to EV purchase, after price and driving range (Dia, 2019). With EV prices declining and longer ranges achieved, the focus will increasingly shift to overcoming the charging infrastructure barriers through stronger investments in charging stations. It is interesting to note that the surveys showed the most convenient location for EV charging is at home. However, workplaces and shopping centres were also identified as potential locations for commercial charging stations.

Stricter regulatory policies

Countries around the world are placing stringent targets on emissions reduction and fuel-economy. For example, China, the world's largest car market, announced it was working on a timetable to ban production and sale of internal combustion vehicles (Dia, 2017; Dia, 2019).

India also declared similar intentions. The two big markets joined Britain and France in making such commitments over the next 15 years. These plans represent government policy shifts that reinforce a shift towards zero-emission driving (Dia, 2017; Dia, 2019).

Blockchain

Blockchain is an emerging technology expected to unleash disruptive and transformational forces in many fields, including transport and freight (Dia, 2016). Blockchain is a shared database or distributed ledger technology in which each piece of new data added to the ledger is attached in sequential order to all previous blocks or chains (ITF, 2021). Blockchain has attracted interest from scholars and practitioners in recent years due to its decentralised nature (Nakamoto, 2008; Dia, 2016a; Yuan and Wang, 2016; Pazaitis et al., 2017; Qi et al., 2017; Lindman et al., 2017; Risius and Spohrer, 2017; Skella, 2018). As a distributed digital ledger, the technology facilitates for stakeholders to carry out transactions transparently. Its real promise in transport and freight is that it can become the underlying operating system that governs how transport and freight systems, particularly contractual and financial arrangements, operate in the future.

Blockchain has several appealing characteristics that have made it particularly promising in many fields such as data security, finance, economy, and transport. These include a decentralised system that removes the need for a central authority to monitor the behaviour of the system; resilience where the entire system does not rely on a single component; and durability against malicious attacks. Blockchain is well suited in providing transparency and trust; ensuring traceability and security as all entries can be publicly viewed; making records immutable to alteration; and ensuring authenticity as transactions are validated before being saved on the blockchain. Enabling access to key transactional information through a private, secure and transparent shared ledger allows transport and freight companies to provide insights into those activities where fraud and manipulation are routine, such as service contracts in the shipping container industry. This can result in reducing or eliminating fraud and manipulation of contracts through the indisputable recording of conditions agreed upon by all parties. By digitising important data and posting it to a blockchain, companies can also decrease or even eliminate the need for unnecessary paperwork. A streamlined, digitised process can provide all parties with safe and secure access to information, prevent fraudulent activity and increase trust.

Blockchain technology also has the potential to improve process efficiency within the transport industry through automation and speed. This facilitates more efficient and better industry interactions among suppliers, freight forwarders, consumers and other stakeholders. The ability to access the same source of information for all parties improves dispute resolution and promotes a sense of trust and collaboration among stakeholders. Blockchain can also offer a decentralised personal data management system that ensures users own and control their data (Kosba et al., 2016; Zyskind and Nathan, 2015). This important property can divert much of the monetary benefits to people who own the assets. Leveraging blockchain technology also improves logistics management across the entire ecosystem by ensuring visibility and transparency throughout the supply chain for all stakeholders. This allows companies to gain insights into the chain of custody, payment information and goods' location from dispatch to delivery. The increased tracking capabilities allow companies to more accurately assess and react to unforeseen circumstances that could potentially affect the supply chain.

Other key uses of blockchain include the domains of governance, transport management, tradable mobility permits, transport consumer payments, advanced traffic congestion pricing, transport priority, platooning and logistics. In this context, blockchain technology can be considered a foundation on which a large number of services can be provided and interlinked.

The implications of blockchain for society and the economy can therefore be widespread and profound as outlined below.

- First, blockchain represents a paradigm shift by removing the need for third-party intermediaries to ensure trusted interactions. Blockchain therefore reduces transactions costs, benefiting society and the economy. The impacts in the transport and supply chain and logistics can be significant.
- Second, the concept of blockchain can unleash a wealth of innovative ideas and business models. For example, the concept of payment in logistics and transport can transform logistics and supply chain systems and make transport and freight mobility highly intelligent.
- Third, blockchain can improve the transport sharing economy (e.g. car-sharing and ride-sharing) with significant gains going directly to people who own the assets, rather than to the companies or organisations that provide the digital platforms and take a cut or commission for linking users and suppliers (Dia, 2016a).
- Fourth, blockchain can be used in the sharing of renewable energy for EV charging where blockchain provides a way for individual households (with their solar panels or batteries) to act as suppliers in the electricity grid network for EV charging (Dia, 2016a, Bagloee et al., 2021).

There are still many challenges that must be overcome before blockchain can become a ubiquitous feature in the transport and freight sectors. One of the main challenges is how to handle scalability as the size of blockchain increases, which is a subject of intensive research. Furthermore, cryptocurrency mining is an expensive operation from an electricity consumption point of view as well as hardware deployment. In order to make blockchain successful in the transport industry, savings need to outweigh the costs of new software and hardware in reconfiguring well-established systems and training, attracting and retaining digitally savvy workers. Other challenges holding back and dampening the initial excitement around blockchain adoption in the transport and freight industries include high costs, lack of proven benefits, missing expertise, and lack of technological foundations and regulations.

Internet of Things

The IoT, or digitising the physical world, has experienced rapid growth in recent years. The IoT has benefited from the fast pace of innovations and scientific advances in a number of areas including sensor technologies, algorithms and data analytics. By converging the physical and digital realms, IoT vastly expands the reach of information technologies and has the potential to change fundamentally the way people interact with their environments. The ability to embed sensors in the physical world makes it possible to monitor, measure, manage and transform the performance of critical infrastructure and processes, saving time and resources and improving the quality of life for citizens.

The impacts and benefits of IoT can be profound. Infrastructure in cities around the world is gradually being instrumented with sensors and devices that communicate with each other in real-time. This offers new opportunities for smart city applications, particularly mobility of people and goods. For example, using IoT-instrumented smart infrastructure, data analytics and algorithms can be used to create smarter vehicles that are connected to each other and to the infrastructure, allowing them to exchange data and enhance road safety. It will also mean smarter trains and public transport systems that are able to sense their surrounding environments and enhance safety in situations where driver error is most common. IoT-enabled smart mobility will also provide travellers with real-time information about public transport schedules, connecting trips, available capacities on arriving trains, trams and buses, and expected arrival times. Benefits will also extend to rail–road level crossings, where a range of train-to-infrastructure and train-to-vehicle technologies can be used to improve safety and provide warnings to avoid collisions. IoT applications in transport and freight can be divided into the following four areas.

1. Traffic control and management. For example, an integrated system of sensors, cameras and vehicles communication are used to control traffic at signalised intersections and monitor real-time vehicle behaviour. Transport and freight applications, in particular, have become the focus of a great deal of innovation and experimentation with IoT technologies in recent years (Chauhan et al., 2016). In freight applications, they can be used for tracking the movement of vehicles and monitoring consignments inside vehicles. In public transport applications, they can track buses and mass transit and use that information to update arrival and departure schedules. When their use is widespread, they will improve vital transport services by monitoring the health of critical infrastructure and identifying potential breakdowns before they occur (Batty, 2013; Dia, 2017).
2. Connected and automated vehicles. This includes an integrated IoT framework for connected vehicles which includes vehicle-to-everything (V2X) communication. IoT is also a key enabling component in automated vehicle hardware and software systems which consists of actuators, sensors, computers, AI self-driving, navigation modules, localisation algorithms and perception systems to detect moving objects.
3. In-vehicle systems. This includes solutions which use information from connected sensors in the vehicle to monitor vehicle conditions, surrounding environment and the driver. Examples include driver smart advisory systems that can be used to monitor speed, detect real-time incidents and provide real-time warning to inform drivers and road agencies of hazardous situations on the road.
4. Predictive maintenance and management of transport infrastructure. This includes IoT solutions which can transform the way our transport infrastructure is maintained through sensors, data analytics and AI deep learning techniques. An example is a system proposed in NSW to assess road conditions in real-time based on an AI neural network support vector machine model (Anaissi et al. 2019).
5. Real-time integrated multimodal travel information. Access to real-time information is available as a result of big advancements in automated vehicle location systems, IoT and mobile computing technologies. An example is the PATH2GO system in San Francisco Bay which provides real-time information about the location of public transport vehicles and estimates of waiting time. The real-time information allows for improved predicted arrival times, which benefit the users who can compare between available modes and decide which mode to use to reach their desired destinations.

Today there are still many barriers to widespread deployment of IoT. These include regulations, cybersecurity, software resilience, redundancy and consumer privacy. Regulations are still required to deal with the modern realities of digital innovations and the interconnectedness of IoT devices. Cybersecurity issues need to be carefully considered during the introduction of new applications. Also, a successful IoT deployment requires a resilient software design and digital networks with less malfunction or errors to support these applications. In addition, personal data is created, transmitted, tracked and recorded across multiple platforms. Hence, governments and regulators need to provide guidance on ensuring data privacy to obtain the full benefits of IoT-enabled smart mobility. Experience from overseas countries shows that successful IoT deployment requires a national-level commitment and recognition of the role of IoT and digital innovations in enabling smart mobility outcomes. Other barriers to overcome include high costs (including maintenance), high levels of technical skills and infrastructure readiness. Other success factors include collaboration between public and private sector organisations and establishment of common standards to facilitate widespread acceptance and technology adoption.

Going forward into the future, IoT solutions will have profound impacts with the introduction of CAVs, and on-demand autonomous shared mobility, AI and data analytics. It will become increasingly important for countries to embark on a national vision and start to formulate policies and strategies to facilitate widespread deployment.

Mobile, cloud and fog computation

Today, the use of mobile internet is widespread with more than a billion people using smartphones around the world. One of the most disruptive innovations in their use is the variety of digital platforms that have enabled connectivity and the proliferation of new business models, subscription services and sharing economy applications. In transport and freight, their use includes travel navigation, travel information, public transport schedules and traffic management capabilities that have enabled users to access a wide range of services and options for their travel such as car-sharing and ride-sharing services. Going forward, their use is expected to include new applications such as cooperative mobility using mobile-to-vehicle or mobile-to-infrastructure communications.

Cloud technologies have also enabled any computing application or service to be delivered over a network or the internet, with minimal or no local software or processing power required. Information technology resources, including computation and storage, are made available as needed, without requiring up-front investment in new hardware. The real potential of the cloud is that it can also enable new business models, including pay-as-you-go services in smart transport and freight services. In transport, the cloud can also improve the economics of intelligent transport and smart mobility solutions for private road operators and government agencies. For example, operations of transport management centres (TMCs) and emergency control rooms can be streamlined through sharing of resources and operational capabilities at reduced costs compared to investments in new centres.

Fog computing, also known as edge computing, is a relatively recent concept that extends cloud computing through a distributed network that facilitates computation, storage and networking services between end (or edge) devices and cloud computing data centres. It effectively includes a distributed network that connects these two environments where it provides the missing link between what data needs to be processed on the cloud, and what data can be analysed locally at edge devices. Fog computing is likely to be a significant enabler in the advancement of smart mobility deployment (Bonomi et al., 2014; Chiang and Zhang, 2016; Datta et al., 2015) including connected and autonomous vehicles (Ahmed et al., 2018; Hou et al., 2016; Cunningham, 2015; Cunningham, 2016). Fog computing also has a number of promising features that include location awareness, widespread geographical distribution, simultaneous network applications, wireless access, streaming and real-time applications. These characteristics make fog computing an appropriate platform for connected vehicle applications in transport and freight (Bonomi et al., 2012; Hou et al., 2016). Furthermore, fog computing can provide enhanced security (Alrawais et al., 2017) which can be useful in addressing some of the technical challenges of IoT and blockchain applications, including the challenge of large databases which limit their real-time application.

Data analytics

The widespread use of connected mobile sensors and devices is providing opportunities to collect large amounts of data in real-time. Generally referred to as big data, the data collected from these devices is characterised by high volumes (ranging from 1,000 gigabytes to 1 petabyte, equivalent to 1 million gigabytes in size); high velocity (in order to be useful, it needs to be analysed rapidly in real-time); and high variety (normally comprising several different sources of data).

The transport sector has always collected and analysed large quantities of data from multiple sources such as map data, weather data, personal location data, public transport schedules, vehicle location data, fare and pricing data, payment or transaction data and smartphone sensors (GPS, accelerometer, camera etc). All of these data sources are expected to continue to play a vital role in urban mobility analysis. However, recent developments in the quantity, complexity and availability of big data, together with advances in computing technology, are presenting new opportunities to create more efficient and smarter transport systems. **Figure**

7 shows the main big data sources and the three component layers required to support smart infrastructure (Hu et al., 2017). The main applications of big data include traffic management, strategic planning, demand modelling, asset management, travel planning, route guidance, disruption alerts, infrastructure management, operational insights and autonomous vehicles. Also, there are some key enablers for big data applications which are imperative to achieve success in this new area such as IoT, AI, ML, advanced analytics (predictive and real-time), blockchain, enhanced computing capabilities, cloud computing and social media data.

There are still barriers to gaining the full benefits of big data applications. These include data availability, openness, usability, accuracy, processing speeds, lack of technical skills for advanced data analytics, privacy issues, data storage, willingness to share, and lack of information on the extent of private sector data availability. When these barriers are removed, the impacts and benefits will be profound and will provide benefits in congestion reduction (savings in time, fuel, improved air quality), safety, efficiency, accurate forecasting and integrated cashless payments on public transport.

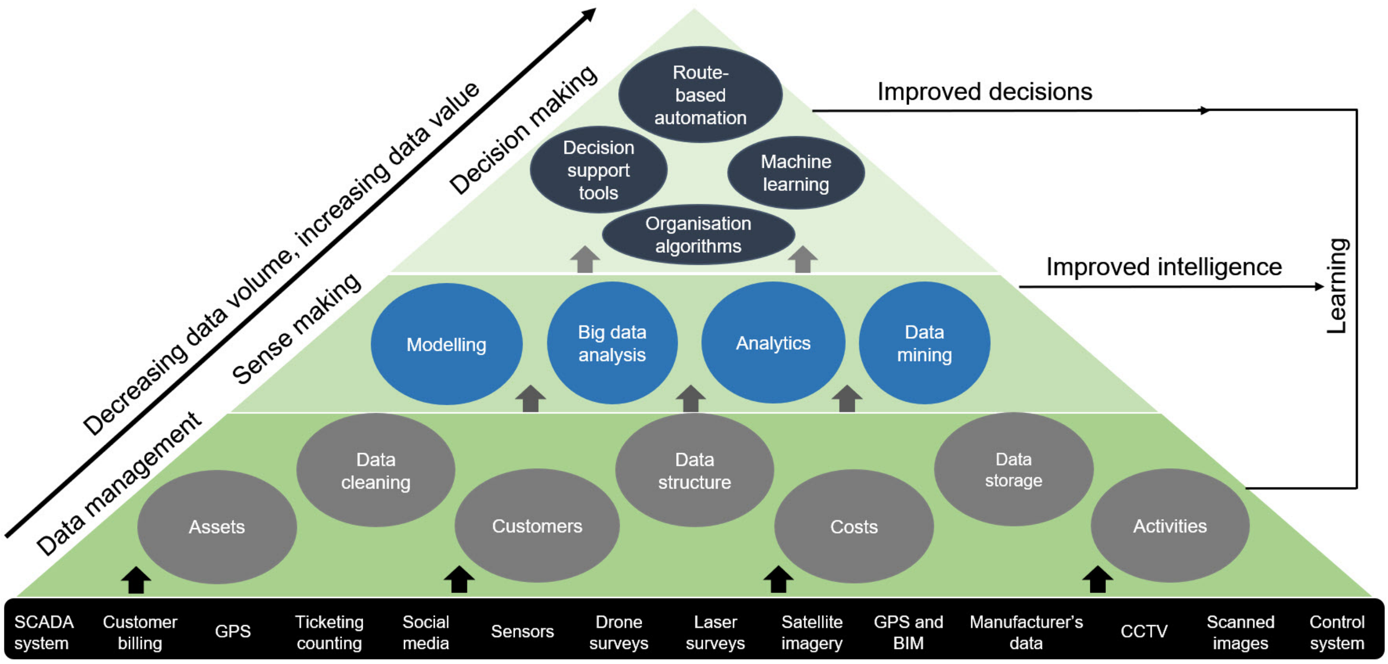

Figure 7: Big data basic layers for smart infrastructure connected by the IoT
Source: Authors. Adapted from Hu et al. (2017)

Mobility-as-a-service and the sharing economy

Shared mobility, and the challenges it poses to traditional car ownership models, is one of the most profound developments and significant trends in recent times that has impacted how people perceive mobility and decide how they move around (Santi et al., 2014; Deloitte, 2014; Owyang, 2015; Goodall et al, 2017; Dia and Javasnhour, 2017). A part of shared mobility's appeal is a growing recognition by travellers that car ownership, especially in urban areas, is not as necessary as it was decades ago. The fast rate of adoption of shared mobility solutions has also been facilitated by the proliferation of digital platforms, which allow people to easily request on-demand services. In particular, new business models of car-sharing and ride-sharing have been made easier and more popular through mobile technology platforms.

Research shows that car ownership is increasingly making less sense to many people (Dia, 2017). Consumers are increasingly challenging the notion of investing in an asset (vehicle) that is under-utilised and stays parked (idle) for most of the day. The new business models, inspired by the sharing economy, are encouraging drivers to shift their behaviour and have started to shape an exciting new era in urban mobility. Innovative solutions such as on-demand car-sharing, ride-sharing, and bike-sharing are all poised to change car ownership models and mobility. The coming together of these trends has the potential to create much broader economic impacts and transform how people live and work.

The appeal of these new solutions is that they can be powerful and easy to implement tools to address the global urban transport challenges. Their benefits include ease of use, convenience, affordability and that they can be on-demand. A number of established and emerging technologies are also helping to expedite their deployment as new forms of public transport. An example is flexible mobility on-demand solutions, including micro-mobility, aimed at meeting personal travel needs through publicly accessible vehicles with flexible routing and scheduling. These shared transport solutions have already started to blur the boundaries with existing forms of public transport, particularly bus operations.

Another promising trend within the collaborative mobility space is MaaS, which represents an integrated mobility solution focused on the individual's needs to travel between two locations. MaaS has evolved from service models which provide vehicle transport without the cost of ownership. The key idea behind MaaS (Burrows et al., 2015) is to offer travellers new mobility solutions based on their individual needs through a single digital platform for combining all mobility options and presenting them to the customer in a simple and integrated manner. This approach has the potential to change the behaviour of consumers and reduce their reliance on car ownership. Instead of owning a vehicle, travellers are provided with a subscription service that provides them with easy access to the mobility services they need. Their key benefits include reliability, convenience, and ease of access. Most services also offer easy and secure payment options using cashless mobile transactions. For a given trip, consumers can select from different types of services based on trip distance, waiting and travel times and required levels of service. Another appealing characteristic of MaaS is integration of both public and private transport solutions (Liyanage et al, 2019) to deliver a tailored package and single platform mobile payments (Kamargianni et al., 2015). Another key advantage of MaaS is that it promotes connected transport services and can offer consumers near door-to-door services.

At a societal level, there are a number of ways these shared mobility services will benefit communities including social, environmental and economical paybacks. Socially, they improve accessibility and equity, and provide flexibility in linking people, jobs and services. They also increase safety and reduce waiting times. From an environmental point of view, they promote sharing and are increasingly being considered a form of public transport that would allow travellers to shift their travel from private vehicles to high occupancy services. These new modes of transport would also reduce the capital costs associated with operations of traditional fleets of buses, while at the same time, providing quality services at lower costs than owning and operating a private vehicle.

Autonomous on-demand shared mobility opportunities

Although fully autonomous vehicles are not ready today, and may take years to develop and deploy on public roads as a viable and safe commercial mobility solution, their arrival will introduce some new opportunities to extend collaborative mobility services. The key advantage of shared autonomous fleets is that the cost of each ride is going to be less expensive because of the lower cost of operating the vehicle without a human driver. A large number of studies have evaluated the impacts of autonomous on-demand mobility (Dudley et al., 2017; Bagloee et al., 2017a; Bagloee et al., 2016a; Javanshour et al, 2018; Leswing, 2018). Recent research in Australia (Javanshour et al, 2018) evaluated the impacts of autonomous mobility on-demand systems using a case study of Melbourne. The results showed that these systems could reduce the city's fleet size by 84% while still meeting the same demand for travel. This, however, comes at a cost of more vehicle-kilometres travelled (VKT). The increase in VKT was found to be significant and amounted to around 77% for scenarios in which the vehicles were used in car-sharing systems, and 29% for the scenarios in which vehicles were used as ride-sharing systems (e.g. Javanshour et al, 2018). These results highlighted the need to take into consideration varying factors of fleet operations to ensure that deployment of new services are optimised and are used in the right context to support and complement existing transport modes. The results from some other studies have also shown that a fleet of autonomous on-demand shared vehicles would produce better results if used in outer suburbs as a first and last kilometre mode of travel. This would entail transporting travellers from their homes to the nearest public transport hubs, rather than competing with existing public transport modes, especially those running in inner urban areas (Dia, 2017).

Artificial intelligence

AI is a broad area of computer science that makes machines function like a human brain (Abduljabbar et al, 2019). AI is used to address issues that are difficult to solve using traditional computational techniques. There are many AI methods used in different applications in transport sector such as knowledge-based systems, artificial neural network systems, ML, deep learning techniques, genetic algorithm, simulated annealing ant colony optimiser algorithms, artificial immune system algorithms, bee colony optimisation algorithms, swarm intelligence systems, fuzzy logic models, logistic regression models and agent-based software engineering. The main enablers for successful AI applications include availability of big data, IoT, computing power and speed, algorithmic improvements, talent and skills, investment and funding.

Today, AI is considered the most profound technological and scientific development over the past decade, with its impacts affecting all aspects life. For transport and freight applications, it is broadly defined as activities devoted to making machines intelligent, where intelligence enables an entity (asset such as a vehicle or infrastructure) to function autonomously and with foresight in its environment. Key AI applications in transport and freight include monitoring the performance of vital services and informing decision making on how to manage assets through large-scale learning algorithms, reinforcement and deep learning, computer vision, data mining, neuromorphic computing and predictive analytics.

In the transport and freight sectors, AI can solve problems that seemed well beyond technology's reach just a few years back. From real-world data, AI machines can learn to recognise patterns that are too complex, massive or subtle for hand-crafted software. AI is also shifting towards building intelligent and resilient systems that can collaborate effectively with people. Smart and connected transport systems powered by AI will enhance resilience through predictive maintenance. Public safety will be improved, with response times to crashes, road closures and other emergencies reduced and harm minimised. Self-healing and self-learning transport systems that use knowledge from historical data to adapt operations and enhance user experience will benefit consumers and travellers by reducing congestion and system breakdown. AI can also help provide meaningful insights, delivered reliably and accurately, to enable transport services to be citizen-centric and personalised (Abduljabbar et al, 2019).

The promise of AI is particularly strong in planning, designing and controlling transport networks, automated incident detection on road facilities, image and machine vision applications such as automated passenger counting and detection, and road safety applications. Advances in these areas will help transport authorities to create a rapid improvement in relieving congestion, making travel time more reliable to their customers and improving the economics and productivity of their vital assets. AI will also help with better detection and prediction of travel patterns, improved traffic forecasts, improvements to public transport (enhanced reliability), integration with shared mobility, enabling MaaS and smart mobility initiatives, on-demand public transport and improved productivity. It is also acknowledged that successful AI implementation requires overcoming significant barriers. These include dependence on the quality or reliability of data, 'black box' effects such as limited understanding of the relationship between inputs and outputs, and resilience in forecasting under unexpected events and adverse weather conditions. Other barriers include computational complexity of AI algorithms, lack of advanced analytics skills, lack of technological infrastructure to support AI, fragmentation and incompatibility of data, data privacy issues, and concerns around job displacement or losses due to automation.

Urban air mobility

Urban air mobility is an emerging field that considers the use of drones, helicopters, staffed and unstaffed small aircrafts and other devices that enable movement of people and goods by air. The growth and success of these solutions will eventually be driven by three major impacts, which include speed and convenience of door-to-door trips (taking into consideration travel time, congestion reduction, security checks, etc.); service affordability compared to other options; and appropriate route coverage. A study by KPMG (2019) showed that urban air mobility can reduce travel time by half for a price just above other premium mobility services. Current research in this field includes development of electric vertical take off and landing aircrafts that use electric power to hover, take off, and land vertically to be used for movement of people and goods. In 2019, Uber selected Melbourne as the first international air pilot city in Australia (joining Dallas and Los Angeles in the US), and plans to start experimenting with Uber Air urban mobility solutions for passenger transportation.

Today, a readily available example of urban air mobility includes small and large size drones, referred to as unmanned aerial vehicles (UAVs), which are flying robots that can be remotely controlled or fly autonomously using software-controlled flight plans in their embedded systems. There are two main types of drones: rotor (tri-copters, quad-copters, hexa-copters and octo-copters) or fixed-wing, which include the hybrid vertical take off and landing drones. Drones are being increasingly used in the transport and freight sector for asset inspections and maintenance of tunnels and bridges, infrastructure maintenance, design process (provision of geospatial data), integration with building information modelling, road construction site monitoring, enhancing construction site safety, traffic monitoring, logistics (deliveries), warehousing and inventory maintenance, remote delivery and disaster response. Successful drone applications require the support of automatous drones, long-life battery technologies, logistic configurations, IoT, and AR and VR.

The use of drones can have significant benefits. For example, bridge inspection is both time-intensive and costly. It also uses heavy duty equipment and causes traffic disruptions. Hence, a drone would provide cost savings and increase safety and efficiency. Other benefits include improving traffic management and resilience of infrastructure, and enhancing data processing and accessibility. However, there are still many barriers to widespread deployment of drones. These include regulatory concerns, safety, security, privacy, anonymity and traceability, misuse (for example, drug smuggling), insurance implications, negative impacts of automation (for example, job losses), and aviation risks (potential for collisions with other aircrafts).

Some of the potential benefits of disruptive mobility solutions are presented in **Figure 8.**

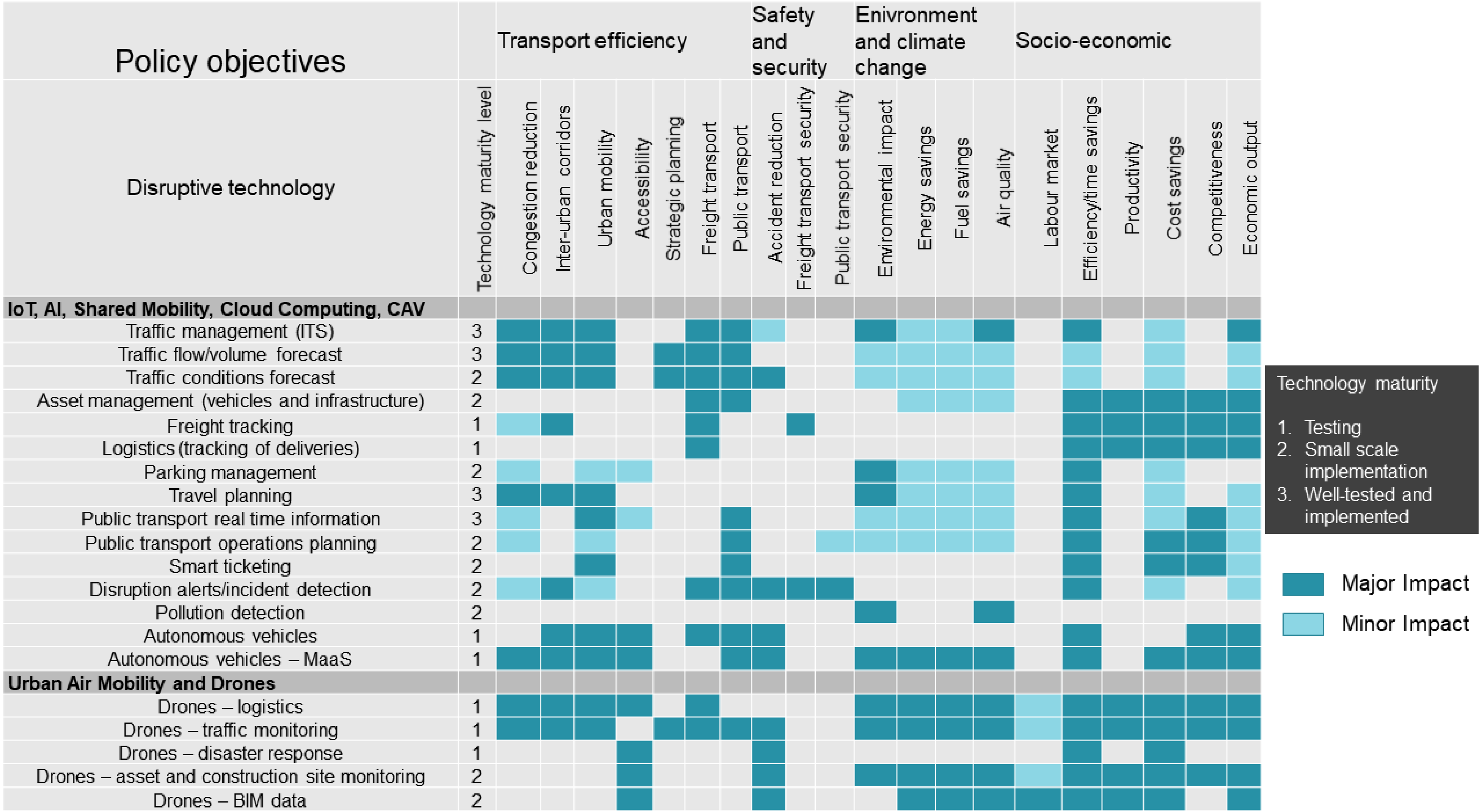

Figure 8: Role of disruptive mobility in meeting socio-economic policy objectives
Source: Adapted from (European Bank for Reconstruction and Development, 2019)

Evaluation of case studies

Evaluation of case studies

This research identified and reviewed a large number of case studies on best practice transport and freight digitisation. **Appendix A** includes summaries of individual key case studies from around the world where before-and-after studies and evaluations have been undertaken as part of the development of transport and freight digitisation interventions and solutions. In this section of the report, the findings from these studies are collated to present overall evaluations for each functional areas. The evaluations are presented in tables, where each table includes:

- the sector functional area under consideration
- descriptions of the relevant interventions in different case studies
- examples of commercial and agency-developed digitisation solutions
- the enabling technologies and digital solutions that support the interventions
- benefits of interventions in terms of productivity gains such as reduction in travel times and delays, reduction in operational costs, reduction in manual processing, reduction in delivery times of goods and services etc.
- maturity levels of the technologies, their reliability, interoperability and maturity of standards
- key countries where interventions were deployed and case studies reported
- BCRs that have been reported in the case studies.

The following considerations need to be taken into account when reviewing these evaluations, and the BCRs in particular.

- Technology and tech-enabled smart mobility solutions have numerous benefits including improving safety, efficiency and environmental performance of transport systems. Smart mobility solutions also generally don't require building or expanding physical transport infrastructure and can provide higher benefits than building new roads.
- The impacts of digitisation interventions are usually established in before-and-after studies. The benefits will therefore depend to a large extent on the baseline conditions for each case study which serve as a reference point to assess current conditions (e.g. extent of current traffic congestion, whether manual systems are in place or some degree of digitisation already exists, or levels of technology adoption in organisations etc). Once the benefits and costs are established, the BCRs are calculated to provide an indication of the relative success of the intervention. In this report, BCRs ranges are provided, where available, to reflect what has been achieved for different case studies. In situations where the baseline conditions were poor (e.g. severe traffic congestion), the benefits of the interventions were typically quite high resulting in larger BCR values. In other situations where the intervention was a system upgrade, a scaled-up solution where baseline conditions were relatively adequate, the benefits were modest but still resulted in BCRs greater than one, justifying the investment. Therefore, the BCR ranges can be used as a guide when considering the possible returns on investment when implementing similar projects in the future.
- Variable methods of measuring benefits and costs, and calculation of BCRs, were observed. These were found to vary across studies and most would not have included wider economic benefits analyses.
- Challenges with international comparisons due to inconsistencies between countries and precision of evaluation methods. In these cases, evaluation of trends over time would be more informative
- Variable levels of technological sophistication that impact the magnitude of benefits. This is demonstrated in **Figure 9** which shows the levels of advancements that could be found in technology and digitisation solutions. Lower levels of technology solutions may include only the ability to sense and monitor. With higher level solutions, the technologies can become more sophisticated and provide additional functionalities such as fast data

processing and initiating control and management strategies. The most advanced solutions include AI algorithms and tools that can be used to provide predictive intelligence and the ability to support self-healing infrastructure and smart assets that allow for predictive maintenance and prevention of breakdowns. Therefore, and as an example, even though two cities may have implemented adaptive traffic signal control systems, the benefits may vary. Benefits depend on the underlying technologies in each system, levels of technological readiness and sophistication, extent of data collection used for system development and testing, and frequency of system maintenance. Benefits also depend on the skill levels of operators in setting up, calibrating and validating the system and monitoring operational performance.

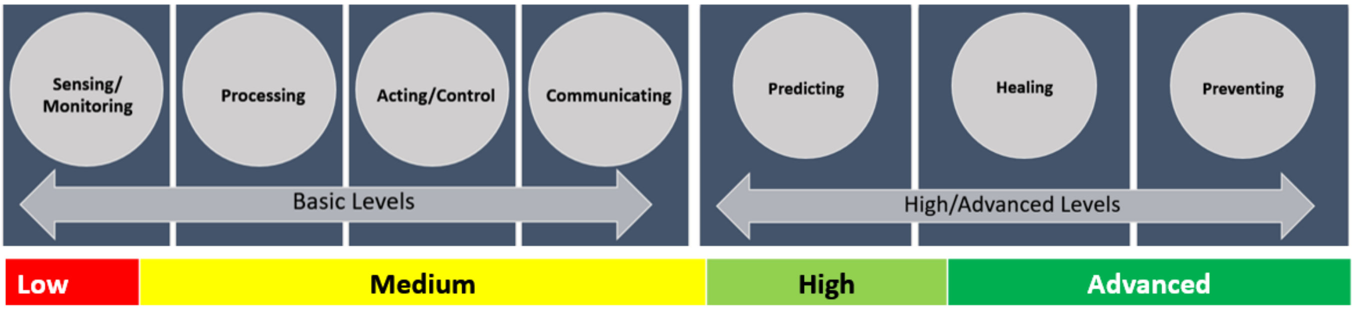

Figure 9: Levels of sophistication of transport and freight technology solutions
Source: Authors. Adapted from Debnath et al, 2014

Road sector functional areas

Road sector	Road safety
Description	Technologies for enhancing road user safety (safe, compliant behaviour), safe roads and roadsides (reduce the risk and severity of crashes), safe speeds (appropriate speed limits that complement the road environment), and safe vehicles (protect occupants, lessen the likelihood of a crash and simplify the driving task)
Example solutions	C-ITS, Intelligent Speed Adaptation, smart signs, roadside collision avoidance, night vision, driver fatigue detection and warning, collision avoidance and in-vehicle safety systems (electronic stability control, active cruise control etc)
Enabling technologies	Mobile speed cameras, wireless communications and video detection systems, C-ITS and automation (automated driving), AI, ML, mobile devices and apps, V2V, V2I, V2X; data collection (image processing methods, drones, and GPS)
Benefits	• Mobile speed cameras: 27% reduction in fatal crashes in Victoria; 20%-25% WA reduction in fatal crashes in WA, 20%-25% reduction in casualty crashes in ACT. • C-ITS applications reduce crashes by 20%-30% (cooperative forward collision warning and curve speed warning), 25%-40% (right turn assist), 35-50% (intersection movement assist). • Automated driving technologies have been shown to reduce crashes. For example, lane-keeping assist and auto emergency braking reduce crashes by 20-40% and 35-50%, respectively
Maturity levels of technology	Varies between technologies. Most are mature except for of C-ITS applications (V2V, V2I and V2X) which are emerging and still under trials
Reliability	Low-moderate: Privacy concerns regarding wireless communications, internet connection issues, the limited ranges and applicability of sensors used in some technologies, systems relying on GPS positioning are subject to the inherent limitations of GPS accuracy and limited by ideal conditions (fine weather, daylight, sealed roads). Technologies for monitoring driver condition may be prone to failure. Warning systems also have the limitation of false positive warnings (driver may become accustomed and ignore the signal or even switch off the technology).
BCR	1-20 depending on technology and base conditions
Interoperability and maturity of standards	High (operating guidelines and standards are well-developed. Good system integration).
Countries	US, Australia, China, Sweden, United Kingdom, Norway, Japan, Denmark, Netherlands, Japan and Singapore.
Success factors	• Trained operators for set up and operations of speed radars and cameras • R&D funding for supporting new innovations such as enforcement technologies to detect risky behaviours, automatic crash notification (e-Call) • Public acceptance • Cost-effectiveness and easy access to technologies including new in-vehicle systems There are opportunities for Australia to ramp up C-ITS trials and safety innovations, particularly in high-speed regional and remote areas where the severity of crashes is higher than urban environments.

Road sector	Road-rail intersection safety
Description	Road-rail intersection technologies aim to improve safety by using advanced warning systems and safety control devices that are implemented in both the infrastructure and also inside vehicles.
Example solutions	Dynamic warning signs (e.g. advanced variable message warning signs), GPS-based train detection systems, mobile detection technique with seismological sensors attached to rails, audible warning devices, obstacle detection systems, in-vehicle warning systems (e.g. collision avoidance systems), automated photo and video enforcement, blinking lights that are activated when a train or vehicle is approaching the intersection
Enabling technologies	LiDAR, CCTV cameras, GPS, communication systems, video analytics, microwave radar, magnetic anomaly and vibration detectors, laser detectors, video imaging, passive infrared and ultrasonic detectors, laser beam sensors, VMS, V2V, V2I, C-ITS
Benefits	• Reduction in rates of crossing violations by up to 36% • Reduction in collisions by up to 70% • Blinking lights (cost-effective low-tech solution): reduction in collisions by up to 20% • C-ITS solutions can prevent 4-15% of crashes
Maturity levels of technology	Mature
Reliability	High
BCR	BCR ranges between 1.11-17.3. For example, BCR 1.44 has been reported for safety devices in a number of US studies; BCR of 4.7 reported for automatic barriers; 1.18-17.3 for simple low-tech blinking lights (infrastructure-side); and some studies have shown BCR between 1.00-1.11 for C-ITS solutions.
Interoperability and maturity of standards	High
Countries	Australia, US, UK, Canada, Brazil, Italy, Germany, Netherlands, Sweden, Japan, Czech Republic.
Success factors	While more work is required to systematically identify a full list of success factors, trials have indicated that they likely include: • High levels of driver compliance and acceptability of railway level crossing warning devices • Reliability of alerts (decreasing false alarms) • Targeted educational and media campaigns to improve driver compliance particularly at high-risk railway crossings • Incorporating redundancy and also designing systems that have combination of sensors such as infrared thermal cameras and LiDAR sensors which have been reported to provide most successful results. There are more than 23,000 level crossings in Australia, many of which involve interactions between trains, road traffic, cyclists and pedestrians. Many states have trialled or implemented solutions with varying degree of success. There are opportunities to develop a national road–rail crossing safety database to document success types of technologies and solutions implemented, before-and-after studies, BCRs and other information to inform decision-makers about investment options.

Road sector	Adaptive traffic signal control	
Description	Intelligent Traffic System (ITS) technology developed to optimise cycle lengths, green times or phasing sequences for traffic signals based on the changing traffic volumes collected from detectors, in order to reduce traffic congestion and improve traffic safety.	
Example solutions	SCATS, Split Cycle Offset Optimisation Technique (SCOOT), STREAMS, OPAC, RHODES, BALANCE, INSYNC, ACS LITE, ATCS, TUC and UTOPIA COMDYCS III, LHOVRA.	
Enabling technologies	Sensors (inductive loops, cameras, radar), advanced hardware and software, communication networks such as 4G, 5G. More advanced systems use advanced algorithms for optimisation supported by data analytics.	
Benefits	• Reduction in delays: 12% (SCOOT), 5-50% (ACS LITE) • Reductions in travel times: 28% (SCATS), 5-25% (ACS LITE) and 9.36% (INSYNC) • Reduction in number of stops: 25% (SCATS) • 15% reduction in CO2 and PM10, and 13% reduction in NOx emissions from vehicles (SCATS) • Increase major street throughput (6.96%) and reduce major street queues (15.57%) using InSync and Synchro Green.	
Maturity levels of technology	Mature. Some systems have been developed in the 1970s and have undergone major upgrades since then	
Reliability	Moderate to High • Functional problems when operated in oversaturated conditions. • Requires human interface to verify efficient operation on all system components. • The processor requires significant up-front configuration, periodic tuning, and regular maintenance.	
BCR	5.4–12.8 depending on level of sophistication of technology and base conditions	
Interoperability and maturity of standards	High: Worldwide adaptation of the systems and it is currently running in: Australia, Bangladesh, Brazil, Brunei, Chile, China, Ecuador, Fiji, Indonesia, Iran, Ireland, Jordan, Laos, Malaysia, Mexico, New Zealand, Pakistan, Philippines, Poland, Qatar, Saudi Arabia, Singapore, South Africa, Thailand, US and Vietnam.	
Countries	United Kingdom, US, Australia, New Zealand, China, Canada, Brazil, Thailand, Chile	
Success factors	• Organisational commitment • Technology and infrastructure investment • Periodic maintenance and updating of cycle plans • Proposer selection of deployment locations • Multiple data sources for redundancy and increased accuracy	Although Australia is using best practice technology for adaptive traffic signals, there needs to be more investment in regular updates of traffic signal plans to respond to traffic growth and changing traffic demand patterns.

Road sector	**Traffic signal priority and pre-emption**
Description	Public transport traffic signal priority involves optimising signal timing or coordinating successive signals to create a 'green wave' for on-road public transport vehicles (buses and trams) as well as providing them with priority to proceed ahead of other traffic when stopped at a signalised intersection. This can include basic passive solutions that require limited investment in new hardware or software, and active priority solutions that are more advanced and rely on interconnected technology solutions that allow public transport vehicles, traffic signals and other control and safety systems to communicate and coordinate actions. Emergency vehicle pre-emption systems are used to provide priority at traffic signals for emergency services vehicles (e.g. police, ambulances and fire trucks). The system is activated by an approaching emergency vehicle sending a priority request to the traffic signal controller.
Example solutions	• TRANSnet in Melbourne which utilises the SCATS traffic signal control system and GPS bus tracking information. • EMTRAC emergency vehicle pre-emption in the US.
Enabling technologies	In-vehicles sensors (tracking equipment including GPS, radio unit), road detectors, geo-spatial detectors, communications systems including radio, cellular, V2I, V2V, V2X. Software and hardware systems, optimisation algorithms and software.
Benefits	• Reduction in delays for buses (25-35%) • Reduction in travel times up to 25% • Reduction in cumulative daily delay for buses by 27 minutes during AM and PM peak periods • Reduction in number of stops made by buses by 3-13 stops on a directional basis by route • Reduction in crashes by around 18% • Increased bus ridership and rider satisfaction by 87%-92% • For emergency vehicles, reduction in average response time by 20%-40% • For emergency vehicles, some studies reported a 10% reduction in the probability of death for each one-minute of faster response.
Maturity levels of technology	High
Reliability	• Moderate but can be increased through regular maintenance and troubleshooting. • GPS location detection can be unreliable/unavailable due to interference from tall buildings particularly inside city centres.
BCR	1.16-11 depending on level of sophistication of technology and base conditions
Interoperability and maturity of standards	High
Countries	US, Australia, New Zealand, Japan, Germany, Romania, Denmark, United Kingdom, Italy, Finland, Latin America, India.
Success factors	• Stakeholder coordination (road and public transport), definition of clear system goals, agree on liability and risk management amongst different agencies • Responsive and proactive team to maintain the system • Using advanced location detector systems • GPS and radio frequency are more affective as detectors than loop and infrared • Software efficiency before full system implantation • Collection of baseline data before implementing the system (to help in undertaking before-and-after benefits analysis) • Optimising algorithms parameters • Implementation of a network of roadside cameras to verify operations System deployment in Australian cities and towns is fragmented. Australian congested cities, in particular, can benefit from widespread deployment and better integration within existing traffic signal control systems. Better results can be obtained when the system focuses on late buses to get them back on time instead of speeding up all buses and creating disruptions to other road users. Best practice also includes deployment of these systems on entire routes rather than only at selected intersections.

Road sector	Network management and control
Description	Network management and control systems include a variety of decision support and incident management systems. Decision support systems provide solutions for real-time operations that rely on real-time data from different types of detectors located in the network that measure speed, flow, travel time and other variables. They also use historical data to make predictions about future conditions. These systems have different levels of sophistication that vary between measurement and monitoring to advanced control and prediction. Predictive systems are amongst the most advanced today and rely on AI and other methodologies to fuse historical traffic and real-time traffic, weather and incident data to forecast short-term traffic conditions. These systems are supported by strategy solutions that determine the set of strategies to evaluate for mitigation of congestion. An important part of network management and control are incident management systems that provide automated detection of incidents (such as crashes or broken-down vehicles) and provide a set of responses to manage the incident such as dispatch of emergency vehicles to remove the incident and restore traffic conditions. This functional area also includes smart parking solutions and technologies to help drivers locate, reserve, and pay for parking.
Example solutions	Aimsun Live, European MULTITUDE Project, Incident management systems such as the Coordinated Regional Incident Management System in the Netherlands
Enabling technologies	Loop detectors, closed-circuit television (CCTV) cameras, video image processing, analytical models, AI, ML, simulation-based models, mobile apps, communication systems including wireless, 3G and 4G
Benefits	1.2% to 2.0% reduction in delays 4.3% to 6.7% reduction in travel time variance 0.3% to 0.7% reduction in passenger hours travelled Automated incident management systems reduce the time to detect incident by 40% Smart parking solutions reduce congestion and emissions by 10% (mainly by reducing the time drivers spend searching for a parking space particularly in congested inner city areas)
Maturity levels of technology	Moderate
Reliability	Moderate. Key issues are related to detector limitations which may be weather sensitive or provide incorrect accuracy during congestion. Similarly, some communication systems have limitations that impact performance including low bandwidth and cybersecurity issues.
BCR	Variable and depends on level of sophistication of technology and base conditions: 1:20 for some decision support systems in the US 1:6 for the incident management system in Auckland, New Zealand 1:4 for some incident management systems in the US 1:21 for traffic incident management systems in Australia 1:36 for smart parking systems in the US such as in San Diego
Interoperability and maturity of standards	Moderate. Key issues remain around integration of multiple systems including different signal systems, detection sensors, mobile sources and ITS devices.
Countries	US, Australia, Spain, UK, New Zealand, France, China, Netherlands
Success factors	• Performance measurement and regular reviews • Automating of alerts for system failures and errors to reduce fault detection and durations of breakdowns particularly for sensors • Project funding and commitment to maintenance and upgrades • Before and after studies to assess the benefits of operations activities • Remote access and supervision of system to allow 24/7 monitoring • Regular maintenance • Modular system design and compatibility with other systems through the use of standard communication protocols on various levels of communication and through publicly available Application Programming Interfaces There are good opportunities in Australia to scale up the deployment of these systems particularly on congested urban roads and networks. This requires strong collaboration between stakeholders, transport authorities and software developers leading to higher acceptance. Advanced network management systems also require skills development and provision of training and technical support to various users and stakeholders to ensure that productivity gains are maximised.

Road sector	Managed Motorways
Description	Managed Motorways (also referred to in some countries as controlled motorways or smart freeways and expressways) include an integrated package of intelligent transport system interventions and ICT that aim to improve safety and reduce congestion. These systems are deployed to actively manage traffic flows and improve road capacity and safety, as well as deliver other important outcomes for road users such as better travel time reliability and real-time traveller information. This includes coordinated ramp signalling, speed and lane use management, traveller information (using VMS), and automated incident detection and incident management. On privately-owned and operated motorways, automatic toll collection systems are also deployed for automatic charging of user accounts without the need for stop-and-go movements which cause delay and increase congestions. Some cities, particularly in the US, also implement dynamically priced express lanes where one or more lanes of an existing facility are reserved for travellers who are willing to pay for the use of the freeway lanes which are usually less congested than the remaining lanes available to the public.
Example solutions	Coordinated ramp signalling, variable speed limits, traveller information systems, lane use management systems
Enabling technologies	Vehicles sensors, CCTV coverage with pan/tilt/zoom camera capability, image processing systems, advanced control algorithms, cooperative ITS (C-ITS), V2I, V2V, V2X, advanced hardware and Software, communication networks such as 4G, 5G, optical fibre cable, data analytics.
Benefits	Motorway capacity increase (5-25%); throughput improvements (1- 20%) and sometimes up to 74%, crash reduction (10-50%).
Maturity levels of technology	Mature (Multiple systems implemented in Australia and overseas)
Reliability	Moderate to High
BCR	1.3- 14.9 depending on level of sophistication of technology and base conditions
Interoperability and maturity of standards	Moderate to High
Countries	Australia, New Zealand, US, Scotland, United Kingdom, Denmark, Germany, China.
Success factors	• Commitment to funding • Proper data management and secure collection of data • Public acceptance • Skills development, staffing and training for installation and maintenance • Performance monitoring • Implementing the technology where it is most needed (location is important) • Good queue detection systems for arterials surrounding the freeway to prevent ramp signalling queues from spilling on arterial roads A number of Australian cities have world-leading best practice in managed motorways including Melbourne, Sydney, Brisbane, Adelaide and Perth. Some cities apply highly sophisticated coordinated ramp metering algorithms (HERO ramp metering system) and have been running some systems for more than a decade with considerable success. To improve productivity gains across networks, funding needs to be committed to retrofit key existing motorways and also for funding to be included in new projects to ensure that the essential digital infrastructure is in place for deployment and future upgrades. Future solutions, assuming acceptance of road pricing and congestion, could also look at dynamic lane pricing.

Road sector	Traveller information systems	
Description	Traveller information systems provide users with information on travel delays, incidents along their route, travel time to their destinations, route guidance, parking information, emergency information and other information that can help them make better decisions about their travel, either pre-trip (before departing) or en route (during their travel). The information is provided on the side of the road using VMS or transmitted to in-vehicle navigation systems or users' smartphones. These systems acquire traffic data from multiple sources, process and analyse the data to derive performance measures to be provided to travellers, and disseminate the information to users. The main objective of these systems is to make a traveller's journey safer, more convenient and more efficient through reducing delays and stress.	
Example solutions	511 traffic system in US, SUNA and Insight Intelematics (Australia and New Zealand),TomTom applications, Multimodal travel information in the Netherlands, PEREX (Permanent Improvement of Networks) in Belgium, TRIM (Traffic Management on the Highways) in Denmark, The 'AddInsight' Travel Time Information System in Australia.	
Enabling technologies	Sensors, CCTV cameras, video image processing, GPS, vehicle re-identification technology, advanced hardware and software, communication networks such as 4G and 5G. Advanced algorithms, data analytics. Delivery of information using radio, TV, the internet, mobile and tablets apps, wireless roadside devices (e.g. VMS) and in-vehicle information systems	
Benefits	Inform travel decision making, reduce travel delays and improve travel reliability.	
Maturity levels of technology	Mature (Already implemented widely in Australia)	
Reliability	Moderate.	
BCR	BCR 1:14.8 reported in some studies for roadside travel information systems. Benefit vary depending on level of sophistication of algorithms and base conditions	
Interoperability and maturity of standards	High (Worldwide applications and Adaptable and responsive to various travellers' needs and uses data from multiple sources)	
Countries	US, Australia, New Zealand, The Netherlands, Belgium, Denmark.	
Success factors	• User acceptance • Data quality and accuracy • Investment in information and communication infrastructure • Financial and technical management • Accuracy of predicted information	Most jurisdictions in Australia have world-best practices in roadside traveller information systems with some room for improvement in estimation of travel times displayed on VMS, and also improvements in speed of communication of incidents and other information to travellers, and regular maintenance especially variable message sign electronic displays. In recent years, travellers have become more reliant on smartphone apps for their travel information needs which are generally more reliable but introduce risks in phone usage while driving. C-ITS holds promise to improving reliability and accuracy of travel information but the current Australian vehicle fleet and infrastructure is not optimised for the types of connectivity required for C-ITS applications.

Road sector	Demand management
Description	Technology-based demand management systems refer to a range of interventions aimed at managing the demand for travel and influencing travel behaviour. This includes solutions to reduce the need for travel (such as tele-commuting) and shifting travellers from private vehicles to public transport (such as road user pricing or congestion pricing). ERP and congestion charging schemes implement technologies that are similar to electronic tolling systems and can include charging per kilometre of travel or duration of travel or congestion charging using cordon pricing (charging vehicles crossing the boundary into a designated zone), area pricing (charging vehicles both crossing the boundary and driving within a designated zone), or fleet pricing (applying targeted pricing to specific vehicle types such as ride-hailing fleets or commercial vehicles that can be applied within a designated zone or citywide.
Example solutions	London, Singapore, Stockholm, Milan and Gothenburg congestion pricing schemes. Portland trial road pricing scheme (RPS).
Enabling technologies	Vehicle detection systems, electronic charging using windscreen e-tag device, automatic number plate recognition, contactless smart card payment systems, passenger occupancy detection technologies, CCTV cameras, infrared sensors, advanced monitoring algorithms, vehicle identification and classification systems, backroom data processing, V2I, V2V, GPS-enabled tolling.
Benefits	10-44% reduction in private vehicle trips in cities that used congestion charging 2.5-22% reduction in GHG emissions as a result of congestion charging Travel time reduction 10%-33% Some congestion charging schemes result in net annual revenues US$20M -US$230M which in most cases are used to upgrade infrastructure for public and active transport solutions
Maturity levels of technology	High. There are current promising experiments with GPS-enabled electronic charging
Reliability	Moderate. Passenger occupancy detection is still a challenging problem (detecting how many passengers are inside the vehicle to confirm if a vehicle is allowed in a certain lane or area or for determining the corresponding charge).
BCR	1.19 for the Stockholm congestion pricing scheme 2.0-2.5 for the London congestion pricing scheme
Interoperability and maturity of standards	High
Countries	UK, US, Sweden, Singapore, Italy, Japan, South Korea, China.
Success factors	• Political and public acceptance • Revenue to be used for improving public transport and active transport infrastructure • Dynamic pricing in response to prevailing congestion and fluctuating traffic conditions • Ongoing monitoring, evaluation and updating of schemes to reflect changing travel demand and patterns (e.g. low emission zones where charging is considered for high emissions emitting vehicles) Although Australia uses cutting edge road tolling technologies, these are mainly implemented on private toll roads to recover costs. Technology-based travel demand management solutions such as road user pricing or congestion charging are not yet implemented in Australia. These interventions have been repeatedly recommended by a number of peak bodies in Australia as potential solutions to ease congestion. They are also becoming increasingly important to consider to address the revenue shortfalls from the declining fuel excise taxes. These shortfalls are attributed to the use of more energy efficient combustion engine vehicles, higher public transport and sustainable transport solutions. The shortfalls are expected to be higher with wider adoption and proliferation of EVs necessitating a different approach for transport taxation through user-pay interventions.

Public transport sector functional areas

Public transport sector	Safety, security, enforcement and compliance	
Description	Digitalisation provides innovative approaches to improve safety and security of public transport including efficient exchange and use of big data to promote a security culture whereby all actors from individual travellers to service providers and infrastructure planners contribute to a safer and secure transport system. The categories under this functional area include passenger safety and crime prevention through technologies for automated monitoring and response; crash and accident prevention including technologies for crash avoidance, better visibility of hazards and active safeguarding by staff; and conspicuous safety measures such as widescale deployment of CCTV and emergency help points.	
Example solutions	• **Driver**: GPS-based technology to track and monitor vehicles, geographic fencing, smart dashcams, live fleet tracking, around-vehicle 360 degree monitoring in real-time, blind spot collision prevention systems, electronic semi and full automation in vehicles, AVL technology used in the event of an accident • **Passenger**: Emergency notification buttons and help points, in-vehicle audio and video surveillance systems, thermal imaging cameras, automatic passenger detection systems	
Enabling technologies	Automation, AI and ML, predictive analytics, smart algorithms and tools, sensors and control networks, vehicle and people detection, V2I communications, data analytics, video analytics and vehicle tracking, blockchain, on-board vehicle sensors for monitoring consignments, algorithms to detect abnormal behaviour in vehicles, smart video protection systems in metro and stations, location-based technologies, thermal imaging,	
Benefits	Positive changes in traveller behaviour at stations. For example, TV screens displaying safety messages achieved an 11.2% positive change in behaviour, silhouette projector imparting verbal safety messages achieved a 19.9% positive change of behaviour	
Maturity levels of technology	High	
Reliability	Moderate	
BCR	1.3 for collision avoidance systems	
Interoperability and maturity of standards	Moderate • Legal limitations – permits for surveillance for some locations, limited storage/retention time regulations	
Countries	Singapore, Japan, Korea, Hong Kong, UK, Canada, Australia	
Success factors	• Investment in enabling technologies and digital infrastructure • Early identification of risks related to data integration, privacy and cybersecurity, and putting in place mitigation measures	Technology and digitisation solutions for safety and security of public transport passengers and operators are advancing at a very rapid rate. These are mainly driven by scientific breakthroughs in AI, machine vision and video analytics. As with other technology advancements, policy and regulations that govern their use around data protection and privacy generally lag behind. Some of the advanced machine vision solutions implemented in other countries, such as those that use video detection for automatic face recognition and tracking of passengers, would need to be carefully considered in terms of benefits versus their potential impact on privacy.

PT sector	Video surveillance and monitoring
Description	The use of CCTV cameras is a proven effective intervention for increasing the community's confidence in public transport and improving the protection of patrons, employees, vehicles, trains, and critical infrastructure. The CCTV system captures and records images (and sometimes audio) of passengers and drivers.
Example solutions	CCTV cameras, video content analytics
Enabling technologies	• Video surveillance systems CCTV cameras – analogue, hybrid, network/IP • Camera technologies such as complex light, light extremes, low-light, tampering, thermal heat, vibrations • Communication technologies including wireless LAN, 3G, Ethernet • Digital recording systems with shockproof, solid-state memory for image storage in a separate unit to improve image retrieval and security • Electronic video systems comprising smart videos that rely on algorithms to profile behaviour, changes lighting/sound condition • Video content analytics including intrusion detection, graffiti behaviour detection, face recognition, left luggage and overcrowding detection • IoT for real-time video data management • Sensors such as radar and LiDAR for driver assistance
Benefits	• Improved safety for passengers and employees, crime prevention and deterrence, reduction in damage to infrastructure and vehicles, reduction of public disorder on platforms and inside vehicles, and detection of unlawful behaviour and inappropriate conduct • Enable investigation of complaints or offences and provide evidence upon which to take criminal, civil and disciplinary actions • Act as a risk management tool against fare evasion and as a defence against fraudulent claims in cases of injury
Maturity levels of technology	High
Reliability	Moderate. Challenges remain in manual monitoring of large numbers of cameras in the public transport system; poor image quality; intensive resource requirements for monitoring; and challenges in responding to incident in real-time. It is expected that AI developments could address this through task automation.
BCR	19.36–31.62 depending on level of sophistication of technology and where case studies have been deployed
Interoperability and maturity of standards	Moderate to High. Challenges remain including legal limitations – permits for surveillance for some locations, limited storage/retention time regulations
Countries	China, UK, India, Singapore, Germany, Moscow, US, South Korea
Success factors	• Networks of cameras deployed across vehicles and infrastructure • Early resolution of privacy and cybersecurity threats and putting in place risk mitigation measures

The hardware solutions used in video surveillance and monitoring systems (such as CCTV and high definition cameras) are largely available off-the-shelf and have become competitively priced in recent years. The key differentiator in performance of these devices, however, is the underlying machine vision analytics solutions that automate data extraction and derive insights. AI techniques, in particular, have proven to be very robust in analysis the vision and deducing measures such as people and vehicle counts, classification of road users, identifying and raising alerts in situations where hazards are identified. In many countries, however, there remain hurdles around privacy protection and cybersecurity but these are gradually being addressed and it is hoped that these issues will ultimately be resolved through stakeholder consultations that include technology companies and community groups.

Public transport sector	Electronic and mobile ticketing	
Description	Electronic and mobile ticketing includes card/media-centric and account-based ticketing. A card-centric scheme is a fare collection system where the funds, proof of travel entitlement, and any primary travel records are held directly on the card. In account-based (open-loop) ticketing, travel records are held in a back-office system on servers, not necessarily on any physical media held by the passenger.	
Example solutions	• Card-centric schemes: contact (magnetic strip) and contactless smart cards • Account-based schemes: pay-as-you-go and contactless bank cards	
Enabling technologies	RFID and Near Field Communications technologies, mobile and connected devices, advanced hardware and software (integrated circuit chip cards and chip card interfaces), cloud technologies, position-based technologies, data analytics, advanced algorithms.	
Benefits	• Reduction in boarding times up to 75% • Reduction in cash handling. For example, in London, less than 1% of bus journeys are paid in cash • Lower set-up and operational costs. No need for investment in heavy infrastructure which contributes to reducing costs • Increased customer satisfaction. More flexible, secure and authenticated transactions; easy-to-use solutions that meet the growing consumer demand to use the same convenient ways to pay for mobility as for other daily expenses.	
Maturity levels of technology	High.	
Reliability	Moderate to High. Some challenges remain but these are expected to be resolved with more advancement in the technology solutions • Validators/terminals need a certain level of intelligence to perform complex functions • Upfront infrastructure investments: High operational costs due to the need to maintain proprietary infrastructure • Integration with third-party systems is often more complex and costly • Data synchronisation is complex due to the distributed nature of the system and takes a long time to get updated data distributed • Losing a travel card means a loss of funds or travel rights on it unless the system manages it through a personal account • Central servers for data management represent a weakness, data intrusion (hacking), demonstrating the strength of this risk • In the case of non-existing communication, the granting of access is linked to a potential loss of revenue	
BCR	1.8–13.33 depending on level of sophistication of technology solution	
Interoperability and maturity of standards	High. The International Organization for Standardization (ISO) has developed standards for smart cards that define the card's physical properties, including size, flexibility, and location of the mag-stripe, magnetic characteristics, and data formats. Similarly, other guidelines are provided by the Smart Ticketing Alliance (STA) Interoperable Fare Management who also promotes cooperation between national-regional smart-ticketing schemes	
Countries	Card schemes are implemented in a large number of cities including London UK (Oyster), Sydney Australia (Opal), Melbourne Australia (MyKi), Japan nationwide (Suica), Hong Kong (Octopus), Montreal and Quebec Canada (Opus), Portland (HOP-fast), Denmark nationwide (Reijsekort), Vancouver Translink (Compass), Moscow (Troika), Singapore (Easylink), Cape Town South Africa (Myconnect), Bogota Transmilenio (TuLlave), The Netherlands nationwide (OV-chipkaart), Chicago (Ventra), Sao Paulo Brazil, Washington (US)	
Success factors	• Ensuring best privacy protection for customers • Avoiding negative impacts of data servers on energy • Ensures improved customer experience • Integration with MaaS schemes and sharing economy	Card-centric ticketing is already implemented in Australia. This includes contactless smart cards MyKi (Victoria), Opal (NSW) and GoCard (Queensland). The Australian Payments Network (AusPayNet) has been instrumental in developing the first version of the framework for open-loop transit, in partnership with Transport NSW. AusPayNet is developing a second version, an Australia-wide framework, for use by other transport authorities.

Public transport sector	Passenger information systems
Description	Passenger information systems for public transport collect and disseminate updated real-time information to passengers on arrival and departure times, potential delays. These systems fuse and integrate data from different sources, some augmented with visual and audio components.
Example solutions	VMS and LCD display screens both on platforms and in-vehicle displays. Passenger information smartphone apps are also today prevalent and provide information on arrival and departure times as well as integration of bus, rail and tram information allowing the user to select from a range of available options to get to their destinations.
Enabling technologies	• LED and LCD displays including coloured graphical representation of information • E-ink is a relatively new technology that provides a graphical image in 16 shades of grey. These displays have vast viewing angles, can be seen in direct sunlight, and have low power consumption making them ideal to be solar-powered. • GPS positioning and AVL technologies, data integrated platforms, automating route diversion and guidance
Benefits	• Enhanced ridership. For example, Citybus services increased passenger journeys in Kuwait by 5% in the first year with the help of accurate real-time information • Reduced complaints and enhanced customer satisfaction by providing accurate and in some cases personalised information • Real-time information improved Stockholm bus passenger satisfaction by 84% • In a survey of Polish passengers, around 67% of respondents believed that better access to passenger information would affect their willingness to use public transport • Better service usage by making travel more accessible and more seamless • Multi-lingual text-to-speech products allow for deployment of passenger information systems with unified messaging, including information streamed to mobile devices and phones that are translated directly to voice announcements.
Maturity levels of technology	High. Smartphones deliver real-time information together with trip planning for people on the move.
Reliability	High.
BCR	BCR 3.3 was obtained in Helsinki (Finland) for a public transport telematics system incorporating real-time passenger information.
Interoperability and maturity of standards	Moderate. There remains interoperability issues between different modes of transport particularly where deployed by a number of agencies or companies within the same city
Countries	France, Germany, Kuwait, Stockholm UK, US, Poland
Success factors	• Enable real-time location and status updates • Ensure passenger satisfaction • Provide more seamless and better service such as text-to-speed The widespread use of smartphones is providing substantial opportunities for App developers to utilise open data standards to develop high end travel information applications for travellers. Governments around the world are facilitating this by providing easy access to data through digital portals (such as data.gov.au in Australia). The past five to 10 years, in particular, have seen an expansion of these systems that are offered both by government agencies (such as PTV journey planner in Melbourne), as well as by private and commercial providers including Google, Apple, City Mapper and other similar services.

PT sector	Personalised public transport and MaaS
Description	Personalised public transport services build on recent trends in transport resource sharing to offer the convenience of near door-to-door mobility similar to private vehicle with costs approaching the level of public transport. Personalized public transport relies on smartphones and an IT platform as a smart form of the sharing economy. Similarly, MaaS is the integration of, and access to, different transport services (such as public transport, ride-sharing, car-sharing, bike-sharing, scooter-sharing, taxi, car rental, ride-hailing and so on) in one single digital mobility offer. These tailor-made service suggest the most suitable solutions based on the user's travel needs. MaaS is available for users anytime and offers integrated planning, booking and payment, as well as en route information to provide easy mobility without having to own a car.
Example solutions	• MaaS data integrated mobility platforms, on-demand services and demand-responsive transport • Dynamic pricing and variable route choices for passengers based on freely-shared real-time information • Mobile applications offering real-time information about vehicles and allowing for ticket purchase and issue and other functionalities • Multi-modal transport systems; integrated, intermodal journey planning; shared use mobility using bike-sharing, car-sharing ride-sharing
Enabling technologies	• IoT, IT platforms on cloud (commercial integrator, transport as the integrator, open back-end platform) • Cloud computing and fog computing, mobile computing, mobile platforms, apps and connected devices • Advanced algorithms for dynamic routing and scheduling, advanced computational power; AI and ML for predictive modelling • Crowd sourcing and data fusion, passenger data analytics, position-based technologies, dynamic pricing and variable route choices
Benefits	• Creates a shift to sustainable modes of transport and travel behaviour. Studies show that private car usage can be reduced by 50% (Ubigo pilot in Gothenburg in 2014); around 26% of participants were more willing to use public transport and 21% were more willing to cycle and walk (Manchester 2018) • Increased PT ridership. For example, ridership increased by 100% for buses, 20% for trains, 5% for trams in Gothenburg in 2014 • More informed travellers through real-time information and enriched travel experience with different choices of transport • High levels of security through identity and access management systems for authentication and profiling of users and devices
Maturity levels of technology	High. These platforms evolved from taxi services, on-demand single passenger services, car/van pooling, and on-demand public transport
Reliability	High.
BCR	Unknown due to the relatively emerging nature of this solution.
Interoperability and maturity of standards	Moderate. Some challenges and barriers remain including regulations and payment integration
Countries	Denmark, Germany, Austria, France, Netherlands, Singapore, US, Canada, Hong Kong, London, Finland, Australia
Success factors	• Ensuring good coverage by positioning personalised public transport vehicles within walking distance and providing last kilometre service • Use of multimodal small form fleets of electrical vehicles including e-bikes, s-scooters and e-cars • Compelling pricing such as subscription-based and pay-as-you-go plans • Efficient fleet management. Operating and managing the fleet of vehicles via a cloud computing service BRIDJ, through its Australian partners, currently operates an on-demand public transport service for Transport for New South Wales in Sydney. The service was the first on-demand service in Sydney to accept OpalPay and concession fares. BRIDJ formerly operated trials in Wetherill Park and a Rose Bay to Bondi service, until they ceased operations on 3 August 2018 and 20 December 2019 respectively. Although this is an emerging solution and is largely in trial mode, evidence in the literature suggests that success factors include utilising smaller size vehicles, improving ability to predict travel demands, route optimisation and fleet management.

PT sector	Multimodal public transport
Description	This includes the use of information technologies and ITS to improve operations of integrated transport systems across multiple modes. This approach helps to overcome the challenges resulting from disjointed operations of services.
Example solutions	• Fare integration. This includes using a single fare card for multiple public transport services to facilitate transfer between modes. • Information integration. This includes a comprehensive, easy-to-use passenger travel information to enable successful multimodal travel
Enabling technologies	Automatic ticketing and information systems, informative and user-friendly websites, online information, online tickets and booking websites; mobile platforms, apps and connected devices, mobile applications offering real-time information about vehicles in motion and allowing for ticket purchase and issue; navigation guidance, interchange guidance, shared use mobility (facilitated among others by apps) including bike-sharing, car-sharing ride-sharing, ride-sourcing). Other enabling technologies include position-based technologies for real-time passenger information, dynamic pricing and variable route choices for passengers based on freely-shared, real-time information, co-traveller information. Other essential components include data analytics, AI (predictive modelling), advanced computational power, ML, algorithms
Benefits	• Results in high modal shares for public transport services (by as much as 59% to 67% in some studies) • Increased system efficiency through decreased boarding time for buses (62% improvement compared to cash payments) • Reduction in congestion as people switch away from the use of private cars thus reducing private vehicle traffic load on the road network • Improving affordability for low-income users and enhancing social cohesion, customer needs and satisfaction
Maturity levels of technology	High. Technologies evolved from primary solutions to enhanced, interactive and coordinated use of digital systems and ultimately fully integrated
Reliability	Moderate to High.
BCR	2.8 (Bern, Switzerland study)
Interoperability and maturity of standards	Moderate
Countries	Singapore, London and Hong Kong success with integrated multimodal public transport
Success factors	• Extensive signage to ensure comprehensive information on all aspects of travelling • Reliable, accurate exchange of information in near real-time • Reduced friction in interactions between multiple systems • Interoperable interfaces for different transport modes • Interchange infrastructure integration particularly in ticketing, where the monetary cost to the user of changing modes is limited or eliminated • Consistent and high-quality signage designed with the user experience in mind • An applied disincentive to car use or ownership such as a congestion charge, taxation and registration costs designed to limit ownership and restrictions of available parking • Delivery of safe, secure and efficient services • An integrated timetable to allow for an efficient interchange • Modal neutrality in transport network decision making – with the best mode selected to suit the task A number of cities in Australia, including Melbourne, Sydney and Brisbane, have had good success with deployment of integrated, multimodal fares which has largely been facilitated by digital platforms and mobile payment systems. Technology companies are also providing sophisticated tools such as Google Maps and Citymapper which provide integrated multimodal travel information that are increasingly adding new features and functionalities to their platforms.

<table>
<tr><th>PT sector</th><th colspan="2">Public transport management</th></tr>
<tr><td>Description</td><td colspan="2">Public transport management applications use advanced communications and information systems to collect data to improve the operation of the vehicle fleet including planning and scheduling, vehicle management, driver management, road track management</td></tr>
<tr><td>Example solutions</td><td colspan="2">Condition-based and status-based maintenance; sensor-based maintenance; remote maintenance; predictive maintenance and automated diagnostic of cause of failure; wayside train monitoring system, network technology for condition monitoring in maintenance; automatically generated maintenance orders; infrastructure monitoring systems.</td></tr>
<tr><td>Enabling technologies</td><td colspan="2">IoT and condition monitoring solutions; sensor technologies for sensor-based maintenance; advanced algorithms for preventive fault analysis; advanced computational power and ML</td></tr>
<tr><td>Benefits</td><td colspan="2">• Faster identification and timely qualification of asset deterioration
• Increased asset availability and optimised maintainability for the operators
• Improved asset reliability and safety, leading to more trust from passengers and a better reputation for the operator
• Lower system life cycle costs; lower maintenance costs through maintenance before failure and only when needed
• Reduction of unplanned outages due to damage resulting in higher availability of vehicles
• Improved system reliability and safety
• Higher operational flexibility can increase transport capacity because of shorter service intervals
• Offer the possibility to monitor asset performance over time</td></tr>
<tr><td>Maturity levels of technology</td><td colspan="2">High</td></tr>
<tr><td>Reliability</td><td colspan="2">Moderate</td></tr>
<tr><td>BCR</td><td colspan="2">1.5–5.0 depending on level of sophistication of technologies and solutions</td></tr>
<tr><td>Interoperability and maturity of standards</td><td colspan="2">Moderate. Some challenges persist including legal and certification issues; organisational issues such as adjustment of processes, and integration into single platforms</td></tr>
<tr><td>Countries</td><td colspan="2">UK, Hungary, France, Spain, Netherlands</td></tr>
<tr><td>Success factors</td><td>• Commitment to funding of capital and maintenance costs
• Training and skill development
• Adequate transmission and communications bandwidth, data accuracy, cybersecurity and open standards
• Adequate data governance and management</td><td>Many jurisdictions in Australia have ageing buses, trains and trams and are also experiencing skills shortages in regular asset maintenance. In addition to the need to upgrade assets and invest in training and skills development, it is equally necessary to invest in high tech capacity signalling and communication-based train control systems on the rail network.</td></tr>
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Public transport sector	Data management and fusion
Description	Public transport operators collect and collate large amounts of data from different sources. This has been facilitated by the emergence of smart public transport cards and the maturity of data management and processing technologies that provide opportunities to uncover hidden information about public transport usage, individual travel behaviours and origin-destination information. Such information can be valuable in understanding travel behaviour and developing new products or services that suit travellers' needs. The types of data include customer data (personal data, travel behaviour data, customer journey data); operational data (operations monitoring and control, disruption management, ticket sales, journey reliability and real-time information, management information, staff information, security data, predictive maintenance of infrastructure, asset and fleet); mobility data (network description, timetable information and accessibility data); and exogenous data (weather, disruptions or scheduling big events, school holidays, sporting events etc.)
Example solutions	ML, deep learning neural networks, data analytics and statistical analyses
Enabling technologies	Data fusion draws on a range of technologies; ubiquitous data logging and sensor platforms, real-time in-stream data analysis, new analytic frameworks, advanced data storage. Primarily, it uses ML and for real-time operations and supervision, intelligent ticketing systems and customer analytics
Benefits	• Fusion of purposely sensed, opportunistically sensed, and crowdsourced data generates new knowledge about transport activity • Enhanced safety through sensors and data storage/transmission capacity in vehicles • Multi-platform sensing technologies can be used to locate and track people, vehicles and objects precisely • Better productivity and higher efficiency • Increased user benefits and improved personalised services
Maturity levels of technology	High
Reliability	Moderate. Some challenges remain including addressing privacy and cybersecurity threats; issues with data analytics related to causality and correlation; bias and representativeness of massive data sets; dealing with the large volumes and speeds at which data is generated, processed and stored; and data protection policies.
BCR	1.3-5.3 (BCRs up to 13 for spatial data)
Interoperability and maturity of standards	Moderate. Some data may be highly structured (e.g. GPS latitude and longitude data and commercial transaction data), facilitating rapid analysis. In contrast, other data may comprise highly unstructured data sets (emails, social media content, video and audio streams) and therefore be more complex and time-consuming to analyse. Advances in data processing and analysis techniques allow the mixing of structured and unstructured data to elicit new insights, but this requires significant effort in data cleaning and pre-processing.
Countries	One of the well-known examples is Rio de Janeiro's Smart Operations Centre in Brazil where data is collected in real-time from multiple sources. The crowdsourced data is overlaid with real-time information from various sensors and cameras to improve mobility operations in the city.
Success factors	• Data quality, investments in human resources including training and skills development; funding; monitoring and maintenance; data licensing; and privacy • Commoditisation of value by selling or producing a service • Indirect value by enriching the type of service or through the development of additional services (such as apps, information, journey planners) to enhance the customer experience • Value accruing to companies that engage in social or market-making platforms enhancing network effects, linking with customers and generating data • Enhancing cybersecurity and privacy protection There are opportunities for Australian transport authorities to invest in multimodal transport control centres similar to the one in operation in Brazil. These centres can also be used as emergency control centres during disasters whereby different government and non-government agencies can be co-located improving decision making and speeding up emergency response.

Freight sector functional areas

Freight	Warehousing and contract logistics
Description	This functional area includes key technology solutions to support primary warehousing functions such as accumulation, sortation, allocation, and assortment of inventory, but also value-adding functions such as packaging, assembly and postponement.
Example solutions	This is an area where technologies such as IoT, information systems and emerging blockchain applications can have a major role in enabling smart warehouses, which can help to boost efficiency and speed throughout the supply chain. Examples include • Warehouse/truck loading automation for load optimisation technology solutions • Mobile/handheld tablets that offer real-time access to warehouse management systems • Handling of inbound and outbound inventory through barcode scanning • Smart contacts including agreement terms, fraud protection, record keeping, payments, cash flow • Digitised documents and real-time shipment data using emerging blockchain-based systems
Enabling technologies	Barcode scanning, RFID, tablets, big data analytics, automation, IOT, advanced imaging and cameras, wearables, cloud computing and voice recognition technology
Benefits	• Improving transparency and traceability in supply chains • Transactional efficiency and improved customer relationship • Automated warehouses with wireless handheld computers can reduce inventory process expenses and reduce processing time by around 25% • Improved order accuracy and on time shipments. On average, warehouses with automated management systems had average order accuracies of 90.6%
Maturity levels of technology	Moderate
Reliability	Low to moderate depending on technology. blockchain, for example, is an emerging technology where some challenges persist in reliability and widescale deployment.
BCR	1.19-1.22 (automated truck loading)
Interoperability and maturity of standards	high
Countries	Singapore, Hong Kong, Malaysia and Australian, Denmark, China, US, UK.
Success factors	• Skills development and training • Widescale deployment and industry adoption through collaboration • Robust standards and governance particularly for emerging solutions such as blockchain • Optimising human-machine collaboration through appropriate planning and design A recent survey of key industry organisations showed that 50% of respondents are looking to implement automated warehouse technologies within the next two years (Konica, 2020). Logistics and warehousing were identified as key areas with greatest potential to adopt AMRs. It is reported that the Victoria International Container Terminal, located at the Port of Melbourne's Webb Dock East, is the first container terminal in the world to offer fully automated operations from the gate to the quayside.

Freight	Last kilometre delivery and urban freight
Description	This functional area includes technologies that support activities in the final segment of goods delivery to the doorstep of customers. Last kilometre delivery is known as the most expensive and polluting segment of the value chain. This is an area that is ripe for technology solutions, particularly innovations that can help reduce costs and improve efficiencies while also reducing emissions and negative impacts on urban transport.
Example solutions	Examples include IoT solutions to help improve performance of urban freight collection and delivery fleets through tracking of vehicles and consignments allowing for demand-responsive operations where the fleets can be redeployed and routed/re-routed in real-time. A range of existing and emerging technologies are used to optimise route and scheduling systems, just-in-time deliveries, onboard real-time vehicle monitoring, AVL, computer-aided dispatch and electronic payments. More recently, platform-based technologies and crowdsourcing mechanisms have received additional momentum in this space to utilise the dormant resources for delivery and storage of goods.
Enabling technologies	Automated, electric and hybrid freight vehicles, ML and AI, autonomous robots, drones, big data analytics, sensors, blockchain, mobile apps, IoT and RFID tags, GPS, Video analytics.
Benefits	• Reduction of emissions by 30% • Improvement in customer experience by 54% • Reduction in traffic congestion through reduced vehicle kilometres of travel (20% reduction) • More informed decision making through data-driven evidence and seamless operations resulting in efficiency improvements by up to 47% in some case studies • More efficient route planning and improved order timeliness and accuracy • Improved driver, vehicle and consignment safety
Maturity levels of technology	Low-moderate. There are currently numerous experiments and trials on automation and pilots on electric and hybrid freight connected vehicles
Reliability	Moderate. Some challenges remain including integration of various systems; removing technical barriers of electric connected freight vehicles such as range limitations; payload volume limitations; and slow-moving legislations in different supporting digitisation areas.
BCR	4.8
Interoperability and maturity of standards	Low to moderate particularly for emerging technologies that are still in the trial phase
Countries	US, Japan, UK, Europe
Success factors	• Commitment to funding and investment in new solutions • Skills development and technical training of staff • Supporting regulatory framework • Data validity and information accuracy This functional area has witnessed substantial rapid growth in the past few years due to the pandemic. Technology will likely have a larger role in improving productivity gains in this functional area through faster and more reliable deliveries and innovations in business models including the use of transport network companies (e.g. ridesharing companies) and peer-to-peer services enabled by mobile solutions and digital platforms.

Freight sector	Trade facilitation and documentation (paperless trade)
Description	This functional area included digitalisation solutions that enable faster, safer and more secure freight across borders (imports and exports). In this area, technologies can have a major role by focusing on simplification and harmonisation of trade procedures and documentation related to exchange between various partners in the supply chain.
Example solutions	Examples include digital technologies for electronic processing of trade documents and related data exchanges. Embedded IoT sensors (e.g. low-cost RFID) linked with data analytics can help to integrate complex inventories into cloud-based platforms. Blockchain technology can also be used to enable deeply encrypted, immutable records in a high-security distributed ledger and help build trust between logistic providers and collaborators. Key facilitating and enabling technologies include distributed ledgers (including emerging blockchain solutions); and business intelligence dashboards
Enabling technologies	• IoT-enabled digital platforms, sensor technologies and cloud technologies • Blockchain for smart contracts, insurance and financial transactions and distributed ledger technologies (DLT) • Robotic process automation
Benefits	• Reduction in manual processing, fewer documents and forms to complete • Reduction in processing time and better utilisation of human resources resulting in lower trade transaction costs • Harmonised data elements resulting in more accessible document transmission between countries and removing language barriers • Improved administrative controls and fewer errors
Maturity levels of technology	Moderate
Reliability	Moderate
BCR	10.88-17.47
Interoperability and maturity of standards	Low-moderate. Challenges remain particularly in use of common international standards across border trade; challenge of harmonisation of different legal frameworks; cooperation between the public and private sectors; lack of coordination mechanisms for cross-border data exchange; different ledger systems that need to be interoperable and integrated with existing systems to be introduced at scale into the financial infrastructure.
Countries	US, Canada, Mexico, Norway, Sweden, Netherlands, Australia, New Zealand, France, Australia, New Zealand
Success factors	• Commitment to funding • Cross-jurisdiction collaboration between stakeholders • Partnerships to facilitate development of financial infrastructures like payment and settlement systems which require industry-wide coordination and collaboration and require significant investments According to the most recent trade facilitation indicators, Australia exceeds or is closest to the best performance across sampled countries in all areas. Performance has improved between 2017 and 2019 in the areas of involvement of trade community, advance rulings, and domestic border agency co-operation. IoT technologies are increasingly being used in Australian supply chain organisations, especially in predictive analytics, process optimisation and cost reduction. There is, however, a strong case to be made for higher levels of transition to automation and electronic trade. A recent survey in Australia showed that 69% of respondent expected blockchain to impact their organisation, and 51% have made provisions for some level of spending on the technology. Blockchain is expected to have the most significant impact over the next 10 years by improving supply chain collaboration (63%) and supply chain transparency (62%). Today, the technology remains at an early stage of development with concerns about its robustness and resilience especially for large volume transactions.

Freight sector	Freight forwarding, aggregation and customs brokerage
Description	This functional area includes technologies and digitalisation applications for routing and scheduling systems, just-in-time delivery, AVL, onboard monitoring and electronic payments. A range of ITS and technology applications are used to improve freight forwarding and aggregation through better planning, loading and efficient route planning. Real-time onboard monitoring technologies and telematics can also help in avoid or reducing the impacts of disruptions.
Example solutions	Comprehensive fleet management including vehicle acquisition and vehicle maintenance, driver analytics including driver safety and compliance, staffing and personnel management, geo-fencing for vehicles and staff, automated passenger count and identification, map view and navigation, next-vehicle arrival times, fuel-consumption metrics, route optimisation
Enabling technologies	• Connected technologies including telematics, IoT, vehicle tracking, RFID, GPS, electronic logging devices • Artificial intelligence: Analytics, forecasting and predictive optimisation, data-driven solutions
Benefits	• Improved fleet efficiency: It is reported that 40-45% of US fleet vehicles are currently equipped with a telematics device, updating operators with real-time visibility into asset location, status, and activities. Telematics-enabled service offerings are already driving fleet efficiencies, where 56% of operators using telematics cite improved productivity and 53% cite reduced fuel consumption as real benefits • Improved ability to better manage fleet assets and organisational workloads • Reduction in total fleet size as a result of better planning and scheduling; and virtual real-time fleet status optimised for scheduling • Improved customer satisfaction through arrival notifications, proof of delivery and fewer billing disputes • Potential elimination of manual processes and greater records accuracy • The possibility of new service offerings not previously feasible, such as in-transit tracking and arrival time projection • Reduced fleet-associated expenses, such as fuel consumption, insurance rates and vehicle downtime • Shortened billing cycles using automation to indicate when the delivery or job was completed • Automated verification for fuel purchase, vehicle usage and timesheet records
Maturity levels of technology	High
Reliability	Moderate to High. Scalability, fault tolerance, privacy issues and cyber-risks remain as key challenges.
BCR	1.1-2.9
Interoperability and maturity of standards	Moderate
Countries	US, Germany, Sweden, Netherlands, Luxembourg, Singapore, Belgium, Austria, UK, China
Success factors	• Data privacy and cybersecurity • Availability of quality data • Commitment to change and to improving productivity • Skills development and technical training A key issues affecting developments in this functional area is lack of unfirm standards for enabling interoperability between different platforms. This challenge is further exacerbated by a continually changing large and heterogeneous landscape of standards relevant for IoT-based fleet and asset management. Innovations in cloud-based systems, embedded software, and machine-to-machine communication is providing opportunities for enhanced data-driven decision-making capabilities. However, the absence of uniform standards to guide developments in these areas will hinder widespread adoption and deployment if not addressed in the short term.

Freight sector	Asset and cargo management
Description	This includes technologies and digitalisation applications such as telematics for tracking and diagnostics, fuel management, health and safety management and dynamic scheduling. This area is characterised by the use of advanced data and video analytics solutions that rely on the mining, collection, and inferences drawn from large stockpiles of information from ships, ports and vehicles in real-time as well as historical data.
Example solutions	Software as a service (SaaS), Cloud-based collaboration platforms (GT Nexus), Predictive Analytics, Procurement platforms (MM4); Tracking services (ATTI, Detrack, Fleetmatics, Traxens, etc.), Cloud-based optimisation (Berlinger)
Enabling technologies	Cloud-based technology (data from the extended supply chain and real-time status updates across the value chain), GPS tracking, real-time visibility of container movements and forecasts Sensors for remote temperature or humidity monitoring (cold chain), Automation, Predictive Analytics, Virtual technologies, Automation and robotics such as robotic process automation (RPA), IoT, ML and AI, RFID, cognitive analytics
Benefits	• Increased transparency including real-time visibility with real-time updates and information. From source to destination, real-time visibility provides excellent insights for manufacturers, suppliers, logistic vendors and end customers of the supply chain • Increased execution efficiency and reduction in waiting times. Getting real-time updates about every stage of the supply chain can enable enterprises to plan and execute strategies more efficiently • Improved customer service. Real-time supply chain visibility can help organisations deliver and maintain exceptional levels of customer service • Reduced handovers and minimised inefficiency. Identifying and resolving issues in real-time is integral to reducing inefficiencies. • Improved informed decisions. Supply chain visibility can help business owners make decisions that are backed by data and insights, thus ensuring smart planning, agile operations, and future-proof strategies. • Improved savings and reduced handling costs. The availability of real-time data and insights at different stages can help save costs and increase revenues or profits. This includes 20-25% reductions in inventory costs due to improved visibility through the supply chain. • Greater access to data due to total visibility
Maturity levels of technology	High
Reliability	Moderate to High
BCR	1.98-3.11
Interoperability and maturity of standards	Low to moderate
Countries	Switzerland, Austria, Japan, Sweden, Netherlands, Germany, Finland, Hong Kong, Singapore, Denmark
Success factors	• Focus on customer experiences such as payment, tracking, delivery and fulfilment which can help deliver a remarkable customer experience, thus improving customer loyalty and gaining a competitive edge in the market. • Robust technical interoperability such as interface specifications, interconnection services, data integration services, data presentation and exchange and secure communication protocols • Creation of consistent, unified data models to extract, cleanse and load both internal and external data from across the supply chain to enable automation, predictive analytics and new business models • Skills development and technical training. This includes encouragement for employees to adapt to new systems create jobs. • Consistent national approach aligned with international standards Australia's supply chains do not stop at state borders. The visibility needs to be extended upstream and downstream to encompass many suppliers and customers overseas. The gains from developing and enhancing visibility along supply chains is particularly relevant for smaller companies that might not have the resources to allow for total transparency, and also for companies who have information in separate silos which are not shared. This allows for the sharing of information to occur at all levels of the supply chain. In order to be effective, data must be relevant and real-time. The pay-back period can be as short as 3 months with a 400% return on investment in some application areas. Going forward, investment in automation and AI will help achieve higher productivity gains.

Freight	Technology-based services for e-commerce support	
Description	This functional area includes technologies and digital solutions that support procurement and delivery of products and services purchased electronically. This includes commerce-enabled apps and websites that provide search capabilities and automated payment systems. Freight transport operators can use advanced technologies to provide easy-to-use interfaces that allow users to determine the most appropriate service based on cost, customer feedback and other criteria. This functional area is supported by warehousing, transportation, and contract logistics services.	
Example solutions	Mobile commerce, electronic funds transfer, supply chain management, internet marketing, online transaction processing, EDI, inventory management systems, automated data collection systems and virtual assistants embedded in smartphones.	
Enabling technologies	Augmented reality, algorithms and data-driven insights, biometric technology, facial recognition, AI and ML	
Benefits	Customer convenience _ approximately 40% of shoppers would be willing to pay more for a product if it offered an AR experience. Around 60% of the consumers would rather buy things at e-shops that offer AR than at ones that don't. Increased sales, conversion rates and larger sales of variety of products sold through online stores Reduced product return Reduced crime and fraud e.g. using biometric technology	
Maturity levels of technology	Moderate	
Reliability	Moderate	
BCR	Unknown. The low costs to implement electronic payment capabilities coupled with opportunities to boost sales, cut costs, and reach a larger audience make implementing digital/electronic payments necessary for businesses to stay competitive in today's marketplace	
Interoperability and maturity of standards	High	
Countries	Australian, China, US, UK	
Success factors	• Provisions for cybersecurity _ regularly updating software and scanning for spyware and viruses. Regular backup systems and information. • Business planning and consideration of how to measure benefits against objectives. • Ongoing evaluations and carrying out user testing to deliver consist positive user experience. • User acceptance through user friendly websites and digital platforms	A 2016 survey revealed that 28% of Australian retailers plan to adopt VR in the near term. However, over half of business leaders surveyed said they did not have a mobile app or mobile-friendly website or e-commerce capabilities. In Australia, increasingly a large percentage of online searches are being completed without a screen (i.e. using virtual assistants)

Rail sector functional areas

Rail sector	Information and communication technology services _ Communication-based train control systems
Description	These include train operations and control by using real-time information on railway conditions, disruptions and incidents that might affect the network capacity. This helps to reduce train schedule disruptions by enabling more responsive train operations and controls that are adaptive to demand and infrastructure conditions.
Example solutions	Train radio for voice and data services between the train and the trackside; train surveillance for monitoring of stations, tracks and passengers; train positioning for the exact determination of the actual train position.
Enabling technologies	Surveillance technology, GPS and mobile communications such as 4G and 5G, signalling and communication engineering, information network platforms, real-time information systems, video and image analytics, automation, high capacity ground-to-train telecommunication, sensor networks
Benefits	• Increased passenger and freight demands as a result of reliable and convenient services • Increased safety and security through real-time surveillance monitoring, which leads to reducing crime and reassures the public and employees • Customer satisfaction through improved passenger services during travel
Maturity levels of technology	Moderate
Reliability	Moderate. The key challenge in IoT implementation is the large number of sensors required and concerns over cybersecurity.
BCR	2.6
Interoperability and maturity of standards	Moderate
Countries	Korea, Singapore, London, France, US, Japan, China
Success factors	• Commitment to investment in digital infrastructure and upgrading of assets • Public-private partnerships particularly in areas related to digital platforms • Sharing of information between different stakeholders • Management of technology deployment risks particularly cybersecurity and data protection Increasingly, train operators are investing more in high capacity ground-to-train telecommunications to facilitate the deployment of systems and technologies for safer and more advanced train network control systems. Technologies and digitalisation are also increasingly used in a wide range of railway services and solutions such as design and development, signalling and communication engineering, video and image analytics, automation, and testing and validation. These tailor-made offerings help railway manufacturers to enhance operational efficiencies, increase reliability, and improve safety across rail infrastructure and operations. Widescale deployment also enables continuous monitoring of train details such as position, speed and direct and continuous transmission of a control command to trains using radio-based train control systems.

Rail sector	Asset condition monitoring
Description	Asset condition monitoring helps rail operators to move from planned maintenance activities toward condition-based and predictive maintenance strategies. This functional area includes technologies for implementing massive IoT systems across the whole rail network to through linking devices inside locomotives, trackside sensors, and back-office computer systems. These technologies also help in monitoring track movements and conditions facilitating predictive maintenance where and when needed.
Example solutions	Real-time condition monitoring, condition-based maintenance, predictive maintenance; asset measurement; asset health visualisation including diagnosis (analysis of asset data and identification of disruption/failure precursors) and prognosis (prediction of upcoming failure and disruptions remaining useful life)
Enabling technologies	Interconnected sensors and diagnosis tools, big data analytics, the IoT, ML and artificial intelligence to allow intelligent and rapid interpretation of data into meaningful information, automation and advanced analytics solutions
Benefits	• Increasing maintenance efficiency. Advanced analytics in condition-based maintenance efficiency have been shown to produce productivity gains of 10-15%. It is also estimated that the global maintenance market can save up to EURO 7.5 billion per year by moving towards condition-based maintenance. Combined efficiency gain through condition-based and predictive maintenance has been reported to be around 15_25% • Reduce manual diagnostics by at least 60% • Condition-based maintenance can lead to an overall reduction of at least 10 to 15% in maintenance costs • Faster identification and timely qualification of asset deterioration; increased asset availability and optimised maintainability for the operators • Improved asset reliability and safety, leading to more trust from passengers and a better reputation for the operator • Improved response times to operational asset faults and failures through real-time asset status views using remote condition monitoring technology • Lower system life cycle costs
Maturity levels of technology	High
Reliability	Moderate
BCR	1.47-1.6
Interoperability and maturity of standards	Moderate to High
Countries	Germany, Japan, France, US, China, Ireland, UK, Canada, India, Australia, Netherlands
Success factors	• Commitment to investment in digital infrastructure and skills development • Accurate record keeping of assets including tracks, tunnels, bridges, signalling, cabling, sleepers, rolling stock etc. This helps with designing reliable predictive maintenance • Ensuring sufficient and reliable transmission and communication bandwidth, data accuracy and cybersecurity provisions The rail sector is no exception when it comes to disruptive changes through digitisation. In the rail sector, fleet reliability is a crucial lever for increasing efficiency and reducing total cost of ownership; therefore, big data and advanced analytics solutions such as condition-based maintenance and predictive maintenance represent real opportunities to yield efficiency gains in maintenance, reducing the number of failures, the amount of unplanned maintenance and, eventually, the required level of reserve asset capacity for rail operators. It needs to be acknowledged though, that the transition from condition-based towards predictive maintenance requires substantial investments in digital infrastructure and skills development.

Rail sector	Operations and track signalling	
Description	This functional area includes cost-effective digital solutions and technologies to help operators eliminate the need for continued investment in outdated railway signal boxes and instead move towards more cost-effective advanced train management and control systems, including providing real-time information to the train driver using in-cabin displays.	
Example solutions	Advanced Train Management System deployed by the Australian Rail Track Corporation (ARTC) and Lockheed Martin	
Enabling technologies	GPS and mobile communications 3G, 4G, IoT, smart phones and apps, AI, sensors, big data analytics.	
Benefits	Improved safety of operations, improved network capacity and improved efficiency of network management Improved prediction of adverse car and track conditions, improving safety, maintenance costs and allowing earlier action on faults Reduction of wait times between trains and safer operation on high risk corridors In Australia, Aurizon's operating costs have reduced by 33% since 2015 linked strongly to the introduction of new technologies, with trip optimising technology reducing fuel consumption by 8% and reducing unplanned maintenance costs by 22%	
Maturity levels of technology	Moderate to high	
Reliability	Moderate to high.	
BCR	2.6 (Automatic Train Control) 1.41 European Train Control System (ETCS)	
Interoperability and maturity of standards	High	
Countries	Japan, US, UK, Australia, Germany	
Success factors	• Single market with common standards, nationally accredited testing, a national industry policy, and industry-standard training • Commitment to funding and investment • Simplifying standards and ensuring they are consistent between jurisdictions • Focus on best practice procurement and contracting • Develop smart rail strategies to build the planning pipeline for digital technology • Skills development and training	Queensland Rail, Aurizon and Transport for NSW are implementing ETCS across their respective networks.

Aviation sector functional areas

Aviation sector	Airport safety and security	
Definition	This functional area includes technologies and digital solutions to support airport security including scanning equipment, airport digital infrastructure and security equipment, cybersecurity solutions, and touchless airport check-in to ensure passenger safety during COVID-19	
Example technologies	Walkthrough metal detectors, hand-held metal detectors, conventional X-ray units, explosives detection systems, explosives trace detection systems, or explosives vapour detection systems. Other examples include smart gates use biometric technology to confirm the identity of passengers and reduce manual intervention at arrival and departure gates.	
Enabling technologies	Metal detectors, backscatter X-ray machines, wave scanners, cabinet X-ray machines, IoT solutions, GPS, sensors, automation, AI and ML, blockchain, robotics, data analytics, digital twins, biometric technology, video analytics, RFID, geo-tagging	
Benefits	Improved safety, efficiency and operations; reduction of throughput time from 2-4 minutes to seconds; faster flow of people through access control without the need for excessive waiting;	
Maturity levels of technology	Mature. These types of technologies are experiencing a rapid rate of development and scientific advancements in response to security needs.	
Reliability	High	
BCR	30 (e.g. Los Angeles International Airport)	
Interoperability and maturity of standards	High	
Countries	US, Singapore, India, Australia, New Zealand, UK, Canada	
Success factors	• Management of diverse sets of data • Skills development and training including AR training • Public acceptance	SmartGates are deployed in international airports in major cities in Australia. These systems help to improve efficiency of immigration processing and improve security. New initiatives now include the Seamless Traveller Project which would see the SmartGates replaced by 'contactless' systems.

Aviation sector	Airport operations
Definition	This functional area is divided into a number of categories that include landside operations, airside operations, billing and invoicing, information management, airfield inspections, pavement management, terminal work orders and runway signage. Technology applications in these areas help to control costs and optimise asset performance, preserving and prolonging the life cycle of vital assets.
Example solutions	Automated gates, facial recognition to identify passengers at automated gates and various checkpoints, automation of immigration processes, digital wayfinding, health monitoring systems, automated luggage scanning and weighing, automated vehicle locations in airport areas, automated robots for maintenance and remote maintenance, remote tools and equipment monitoring; fully automated self-service bag drop; automated runway inspections using laser scanning equipment
Enabling technologies	IoT, GPS, sensors, automation, AI and ML, blockchain, robotics, data analytics, 5G, digital twins, biometric technology, video analytics, RFID.
Benefits	• Improved operational efficiency by using data on the current condition of airport facilities. For example, sensors will transmit data such as amenity shortages and breakdowns to alert facilities management to respond to those issues; • Reduction in operational costs by improving productivity with better operations planning; • Optimisation of demand at the airport by improving crowd control and automating passenger controls at checkpoints. • Enhanced passenger experience at the airports. For example, the availability of wayfinding and information in different languages (through digital displays, robots, etc.) helps to provide international passengers with more convenient travel • Acceleration of check-in times and improve services for passenger processing. • Improved monitoring of security, safety and reliability of operations and maintenance. • Improved health monitoring and ground services (cleaning frequencies, amenities availability etc.).
Maturity levels of technology	Moderate to high. While current technologies in place in airports are mature and have been implemented in airports around the world, the technology is still improving to meet increasing safety and security requirements.
Reliability	Moderate. Some challenges remain including data privacy risks
BCR	1.0-4.0
Interoperability and maturity of standards	High
Countries	Australia, China, Japan, US, UK, Canada, Europe
Success factors	• Undertaking extensive trials before integrating new technologies in smart airport operations • Development of management strategies to upgrade existing airports with technologies and address all risks. For new airports, all requirements should be met prior to starting operations. • User acceptance of technologies including facial recognition or advanced screening. Gradual introduction of automation can help increase user acceptance • Skills development and training • Deploying robust systems to eliminate cybersecurity risks, while improving collaboration with law enforcement to detect safety and criminality risks. • Legislative frameworks to protect sensitive data and privacy Majority of Australian airports already implement key technologies in this area including self-service check-in, baggage drops at automated kiosks and SmartGates. Most of new technology investments are driven by security concerns. Some key challenges which require infrastructure solutions, including improvement of traffic circulation at drop-off and pick-up locations and improved handling of limousine and ride-sharing services, will need to be designed to include digital solutions to optimise performance and manage demand.

Aviation sector	Capacity management
Definition	Airport capacity planning and assessment refers to all activities related to the capability of an airport system to handle a certain demand in flight and passengers. This functional area includes real-time monitoring of passenger flows within airports. A good understanding of flows between terminals and within airport facilities can help in the design of better infrastructure facilities that improve flows and movements and reduce stress levels and inconvenience for travellers. Innovative web-based tools are available that can improve the way airfield capacity interacts with key interfaces such as ground infrastructure and terminals. The technologies in this section help airport operators assess the impact of various factors on performance such as scheduling. Research over the past 20 years has yielded increasingly sophisticated optimisation models for application at individual airports.
Example solutions	• Swiss-based company Xovis which has equipped 293 sites, at 61 international airports with the Xovis Passenger Tracking System • Airport capacity management models such as operational modelling like mixed-integer programming, queuing theory and heuristic optimization. • SESAR and NextGen programs in Europe and the US aimed at increasing the capacity and efficiency of air traffic management systems.
Enabling technologies	Video analytics (biometrics, thermal/visual fingerprint, visual light spectrum), Global System for Mobile Communications (GSM), ML and AI, algorithms, mobile apps, IoT systems, 3D sensors and software solutions. WiFi, Bluetooth or imaging-based flow monitoring, indoor geo-localisation, data analytics and advanced simulations.
Benefits	• Reduction in queue lengths through predictive staff scheduling and better deployment of resources • Increased operational efficiency through analysing passenger dwell time patterns and passenger flows • Increased non-aeronautical revenues from better understanding of passenger behaviour and delivery of location-based marketing • Enhanced passenger experience from being better informed on waiting times • Real-time data allows airport operators to remain in the know on queueing situations and take proactive measures • These solutions helped increase Helsinki Airport annual passenger throughput from 19 million to 30 million
Maturity levels of technology	Moderate
Reliability	Moderate. Some technologies only track passengers within a contained area and there is no potential to identify or communicate with passenger. Another challenge is system accuracy. Light sources or sunlight reflections can impair the technology without being able to centrally detect such occurrences. The systems also require expensive computing and storage servers compared with alternative technologies
BCR	10.8-17.5 (TBC)
Interoperability and maturity of standards	High
Countries	Australia, China, Japan, US, UK, Canada, Europe
Success factors	• Skills development and training • Ensuring accurate, reliable and updated information on passenger demands • Regulations covering privacy and algorithmic transparency • Regular checks of automated measurement solutions to guarantee a steady level of high-quality data This is an area that is ripe for increased digital innovations and technology solutions. While most Australian airports already have good levels of digitisation services to deal with these challenges, travellers are increasingly expecting higher levels of service and efficiency for the processing of passengers and freight.

Maritime sector functional areas

<table>
<tr><th>Maritime sector</th><th colspan="2">Safety and security</th></tr>
<tr><td>Description</td><td colspan="2">This functional area includes technologies and digital systems to improve maritime surveillance capabilities, collect information about maritime incidents, and improve the safety, security and law enforcement activities to safeguard shipping ports from unlawful activities.</td></tr>
<tr><td>Example solutions</td><td colspan="2">High-frequency maritime surveillance radars; Coast Control Surveillance System, Maritime border surveillance and integrated maritime surveillance; SAFFiR – Shipboard Autonomous Firefighting Robot developed by the US Navy Research Lab in collaboration with Virginia Tech</td></tr>
<tr><td>Enabling technologies</td><td colspan="2">• Surveillance systems and drones; high-frequency radars; 4G and 5G communications
• Automatic identification systems, automation and unmanned systems for vehicles and infrastructure
• Real-time monitoring, RFID and sensor technologies, predictive analytics
• Unmanned ships and automation; airborne and underwater drone technology
• IoT and data analytics for intelligence collection and analysis
• Condition-based maintenance systems and Predictive maintenance systems</td></tr>
<tr><td>Benefits</td><td colspan="2">• AI can help reduce the 75%-96% of marine accidents that involve human error
• Safer working environment, safer shipping, detection of illegal goods and suspicious activities
• Automation reduces the risk of accidents. AI can be used to analyse data to create a safer and risk-free work environment
• Coast control surveillance systems helps to prevent vessels from entering prohibited areas, and monitoring import and export goods</td></tr>
<tr><td>Maturity levels of technology</td><td colspan="2">High</td></tr>
<tr><td>Reliability</td><td colspan="2">Moderate to High</td></tr>
<tr><td>BCR</td><td colspan="2">1.41-8.10</td></tr>
<tr><td>Interoperability and maturity of standards</td><td colspan="2">Low to moderate</td></tr>
<tr><td>Countries</td><td colspan="2">US, Netherlands, Germany, China, Italy</td></tr>
<tr><td>Success factors</td><td>• Sophisticated surveillance, mapping, and monitoring
• Use of virtual and AR to predict risks of accidents and ensure the safety of vessels, passengers and cargo
• The use of IoT analytics, AI and 5G communication technologies in technical and nautical operations including e-navigation, berthing, and collision avoidance
• Increased automation, decision support, remote monitoring to boost safety and operational performance
• Skills development and training for advanced monitoring of container traffic and risk analysis including detection of suspicious shipments, customs fraud
• Secure data sharing through online platforms
• Integrated maritime policies for facilitating surveillance and data collection (good example is the European Marine Casualty Information Platform) where maritime accidents involving member states ships are registered
• Improved cybersecurity solutions</td><td>The maritime sector can generally benefit from improved data standardisation and interoperability to enable secure data sharing amongst different stakeholders. Standards such as UNCTAD and Digital Container Shipping Association (DCSA) can help to enable end-to-end interoperability, allowing supply chain participants to digitise data and send and receive it in understandable and usable ways. There is also room for creation of Open Standards that allow entrepreneurs to adapt and implement advanced systems such as blockchain-based information exchange solutions which can also help address cyber attacks in the shipping industry which is critical for the reliability of operations as well as data privacy protection.</td></tr>
</table>

Maritime sector	Port operations	
Description	This functional area includes IoT applications and other technologies that enable the leveraging and fusion of data from different sources including tidal data and pollution levels to help decision-makers in managing port operations and enhance the utilisation of port assets and facilities, equipment for cargo handling, berth facilities, waterways, and roads.	
Example solutions	Port Community Systems (Port Authority of Singapore, National Trade Platform), Single Window (Jebel Ali, United Arab Emirates), Port authorities as digital service providers (Hamburg SmartPort)	
Enabling technologies	IoT/sensor networks, 'intelligent' buoys (collection of tidal data, temperature, pollution levels), RFID, Robotics, Automated stacking or STS cranes, air and underwater drones for inspection, automatic identification and container detection technologies, blockchain for contract verification, automated shipping, data analytics for port administration, VR and AR for digital twins, video surveillance and AI for facial recognition, container monitoring, robots and UAV patrol, and autonomous trucks	
Benefits	• Increased port handling efficiency and high productivity using automated port terminals, automatic identification and detection of containers • Reduction of accidents leading to safer working environments and safer shipping by using automation and AI to fuse data and create risk-free environments that adapt to real-time conditions. • Increase productivity by speeding up ship docking. Also, clearing more cargo per hour with a reduction in load times (loading and unloading) • Savings to operators exceeding US$80,000 each time they dock a vessel achieved through advanced communication of cargo information • Faster and more informed decision-making through technology • Reduction in container handling and improving yard and equipment usage • Improved tracking of maintenance on ships and prediction when parts may break down using AI-based predictive maintenance • Reduction in ship waiting times by enabling just-in-time operations • Reduction in costs. This includes new approaches using blockchain to reduce cargo documentation costs	
Maturity levels of technology	High. Most best practice solutions have evolved over generations of technologies progressing from paper to paperless procedures, through automated practices and finally into smart blockchain-based procedures.	
Reliability	Moderate	
BCR	1.98_3.11	
Interoperability and maturity of standards	Moderate	
Countries	China (Shanghai), Singapore, Netherlands (Rotterdam), US (L.A., New York), Germany (Port of Hamburg), UK (London, Portsmouth), Australia (Brisbane, Sydney, Melbourne), Japan (Tokyo, Nagoya), Taiwan, Belgium (Antwerp), Korea (Busan), Spain (Algeciras, Barcelona), United Arab Emirates (Abu Dhabi, Dubai), Panama, New Zealand (Auckland)	
Success factors	• Recognising the changing role of ports and terminals from asset management to serving clients and creating additional value • Improving co-ordination between stakeholders particularly traffic management around ports • Targeted solutions that address key challenges such as automatic identification and detection of containers, AI and data analytics for real-time decision making, use of blockchain to streamline customs information and documentation • Enabling innovations in just-in-time operations including optimisation of ship operating speeds to arrive at its port only when a docking space is available.	Ports that are taking the lead in automation in Australia include Brisbane, Melbourne and Sydney. Australia's ports can generally achieve substantial productivity gains when opting for a collaborative approach to rolling out connected smart ports. A key challenge is to evaluate the competitive potentials of comprehensive and consistent digital strategies and integration with the existing port Information technology and system infrastructure. This demands a high degree of Information technology and system knowledge and expertise.

Maritime sector	Administrative procedures	
Description	This functional area includes advanced technologies, software and digitalisation solutions that can be used in maritime administrative procedures for faster booking, paperless documentation, and coordination of administration procedures. Examples of technologies used include predictive analytics to forecast demand cycles, booking allocation management, vessel deployment, rate analytics and instant freight quotes, online booking and blockchain for smart contracts, insurance and financial transactions. This also includes paperless customs administration and software for customs load identification.	
Example solutions	Booking platforms (Inttra); rates technology platforms (CargoSphere with confidential rates information transmission, Coyote with crowdsourced open rates); Smart contracts/blockchain (Ethereum); paperless processing of cargo information (Dubai trade platform); and distributed ledgers	
Enabling technologies	• Predictive analytics to forecast demand cycles, booking allocation management, vessel deployment • Blockchain for smart contracts, insurance and financial transactions • DLT • Visual software for customs load identification	
Benefits	Faster booking, reduction of paperwork and better coordination of administrative processes	
Maturity levels of technology	Moderate to High	
Reliability	Moderate. Challenges remain including risks of cyber attacks and scalability of advanced solutions	
BCR	10.88-17.47 (private and public blockchain DLT in global payments)	
Interoperability and maturity of standards	Moderate	
Countries	South Korea, Japan, Singapore, United Arab Emirates, Netherlands	
Success factors	• Decentralisation using DLT which can reduce inefficiencies and paperwork related to organising a shipment. • Improving data privacy, transparency and cybersecurity to allow for better data sharing • Commitment to funding digital infrastructure projects • Stakeholder coordination	Shipping supply chains in Australia still rely heavily on manual paperwork. This makes the information flow inefficient and vulnerable to potential alterations or information being lost. DLT are increasingly being used to address this issue but these systems will need to be interoperable with other ledgers and integrated with existing systems to be introduced at scale into the financial system. The cost of integrating DLT into financial infrastructure like payment and settlement systems will require industry-wide coordination and collaboration and substantial funding.

Maritime sector	Ocean and short-sea shipping
Description	This functional area includes technologies and solutions to support ocean and short-sea shipping. Short-sea shipping includes maritime transport along the coasts and between the mainland coasts and islands, covering purely national transport, cross-border services and sea-river transportation by coastal vessels to and from ports in the hinterland. This includes barging (transport using national or regional canal networks; inland waterways (rivers, lakes or major international canals establishing the links between these rivers); and short-sea shipping using ferry shuttle services between two ports. Deep sea and ocean shipping refers to the maritime transport of goods on intercontinental routes, crossing oceans.
Example solutions	Vehicle automation in ports (battery-electric automated guided vehicle) and gate automation (e.g. Jabal Ali in UAE)
Enabling technologies	Gate automation systems, real-time data on traffic and algorithms to operate traffic signals, slot management based on forecasts, storage capacity sharing, autonomous trucks, unmanned ships, semi-autonomous or autonomous vessels, IoT, RFID, GPS, short-range wireless container tracking
Benefits	• Better visibility into planned truck or rail movements • Exploiting underused storage capacity • Allow shorter turnaround times in ports and hence reduce travel time and transport cost • Ability to reach 'peripheral' regions that are impossible or difficult to reach by other modes • Short-sea shipping is a significant source of employment (accounting for almost 60% of French sea-going jobs)
Maturity levels of technology	Moderate
Reliability	Low to moderate.
BCR	1.7
Interoperability and maturity of standards	Low to moderate.
Countries	Netherlands, Belgium, Turkey, Sweden, Singapore, Korea, United Arab Emirates
Success factors	• Mutual cooperation and agreement between land and sea transport • Harmonisation of rules for land-sea carriages of hazardous goods, incorporation of short-sea shipping into transport infrastructure planning and integration of seaports as multimodal interfaces • Charging of road-related and external traffic costs to users as a prerequisite for undistorted intermodal competition in favour of environment-friendly modes of transport • Productive use of all available information gathering from ship sensors • Reducing the uncertainty interval regarding the arrival of ships in port by optimising the entire workday while considering actual demand and the terminal's operations • Centralised traffic systems for vessel traffic management Shipping is perceived as a slow-moving industry when it comes to technology adoption. Key impediments include road intermodal competition and technological barriers in allowing different modes to compete on equal terms. This is further complicated by ageing assets and lack of purpose-built vessels (between 57 and 72% of the fleet used for short-sea shipping are reported to be multipurpose vessels). The sector is also beset with lack of transparency which makes it difficult and complex to organise. Technology is expected to play a major role in enhancing fleet productivity and profitability through digitalisation and also by using new technologies such as unmanned vessels. Technology can also assist in improving the cargo handling procedures and exploiting underused capacities in ports through opportunities for new business models and digital platforms.

Maritime sector	Maritime traffic management
Description	This functional area includes digital solutions and technologies that can be used for sharing information and improving collaboration between stakeholders in order to optimise the maritime transport chain and increasing safety and sustainability
Example solutions	IoT Applications for ships (IBM, Hyundai Heavy Industries); ship information management systems as open platforms accessible by third parties; vessel traffic management information systems; information services (essential and timely information to assist the onboard decision-making process); traffic organisation services (detect dangerous maritime traffic situations and allow the safe and efficient movement of vessel traffic); navigational assistance services (essential and timely navigational information to assist the onboard decision-making process and to monitor its effects); and maritime assistance services (handling incidents of vessels in difficulty).
Enabling technologies	IoT (sensors for self-diagnosis and reporting capability of equipment, i.e. for predictive maintenance and remote support); artificial intelligence – neural networks and optimisation algorithms; big data; cloud and edge computing; satellite technologies; automatic identification systems; voice-controlled devices (communication, remote sensing for optimal paths, navigation, weather conditions); and telematics (tracking and diagnostics, fuel management, health and safety management, dynamic scheduling, etc.)
Benefits	• Better visibility of equipment conditions • Improved safety • Environmental efficiency and reduced carbon footprint by choosing environmentally friendly carriers • Better coordination with ports/pilots
Maturity levels of technology	Moderate to high
Reliability	Moderate
BCR	5.1-10.2
Interoperability and maturity of standards	Moderate
Countries	US, UK, Singapore and China. It is reported that 96% of almost 3,000 patents relating to autonomous shipping technology worldwide were registered in China. In Singapore, a ship-to-shore pilot project, which deployed drone technology in real-time port conditions, was used to deliver a variety of small, time-critical items to vessels anchored in port as well as commercial drone delivery to the vessels.
Success factors	• Operational efficiencies that have been introduced through technology and automation which facilitates remote command and control centres • The readiness for automation has been attributed to a number of measures including innovation and technology, infrastructure quality, regulation and governance, human capital and skills, and business and investment. Shorter times spent by vessels in ports represent a positive indicator of a port's efficiency and trade competitiveness. A number of studies have reported that the lowest levels of performance in terms of times spent by vessels are represented by France (41.8 hours), Italy (36.5 hours), Australia (34.6 hours) and Brazil (33.6 hours). According to these studies, there is also a readiness gap between developed and developing countries in the maritime sector. Higher levels of readiness were observed in Australia, East Asia, Europe and the US. In contrast, countries in Africa and South America were positioned at the other end due to insufficient technological advancement, investment, agile regulations and infrastructure gaps and weaknesses in terms of business models.

Active transport functional areas (Emerging)

Active transport sector	Safety of riders and other vulnerable road users
Description	This functional area includes technologies for the safety of micro-mobility devices (tiny vehicles) and other road users. These include solutions to prevent sidewalk riding and to limit speed in pedestrian areas
Example solutions	Pedestrian detection cameras mounted on micro-vehicles; smartphone app to alert their passengers to the presence of bike lanes; anti-lock braking systems installed on all micro-vehicles; bells and other acoustic alerting systems, electronic sound activated by a button; electronic stabilisation to strengthen steering resistance at higher speeds and apply a corrective steering input when a fall is predicted; intelligent speed assistance; autonomous emergency braking; helmet wear detection system (camera-based AI system used to reward people wearing helmets); geofencing; customisable lighting system that is embedded underneath the standing deck to increase safety level of night-time riding
Enabling technologies	AI, ML, Cameras, Video analytics, Vehicle sensors, GPS, WiFi, and 5G, 4G, RFID, Computer vision and video cameras, algorithms, V2V, V2I.
Benefits	Anti-lock braking systems resulted in a 33% reduction in all crash and injury severity, and 39% reduction in severe crash injuries. For the few cases where anti-lock braking systems and braking systems were combined, the reduction was higher at 44%.
Maturity levels of technology	Moderate.
Reliability	Low-Moderate. Challenges remain regarding data sharing and privacy. Most emerging technologies are still in trial phases.
BCR	3.0-4.9 anti-lock braking system 1.3-1.5 autonomous emergency braking 2.0-4.8 speed assistance systems
Interoperability and maturity of standards	High.
Countries	Germany, China, Sweden, Australia, Singapore, Denmark, Portugal, Estonia, France, Hungary, Italy, Latvia, Poland, Austria, Czech Republic, Finland, Lithuania, Slovak Republic, Slovenia, Spain, US
Success factors	• Agile regulations that allow safe introduction of micro-mobility solutions • Undertake road safety audits of street networks where micro-mobility solutions are introduced • Public acceptance • Provision of financial incentives to users who follow guidelines particularly safe parking of their devices in designated spaces away from sidewalks Active transport solutions are increasingly being adopted by travellers in Australian cities, and their use has particularly increased during the pandemic. E-scooters, in particular, are seen as a potential disruptive mobility solution due to the likely role they can play in disrupting short distance travel and commutes by private vehicles. Safety, however, remains a key issue for riders and vulnerable road users. A large number of trials are underway in Australian cities including Darwin, Canberra, Melbourne, and Adelaide. Technology developments in this space will play a key role in risk mitigation. While these technology solutions are being developed by technology companies and service operators, they need to be supported by agile regulations and policies.

Active transport sector	Parking management	
Description	Parking of e-scooters and micro-mobility devices, especially those offered as shared services, remains a contentious issue. They are often parked on sidewalks where they clutter available the space available for pedestrians and reduce safety. Technology offers a number of solutions including parking allocation supported by financial incentives	
Example solutions	Camera-equipped scooters that can sense if the device is not parked in an upright position within the specified parking zone. The app can then notify users to re-park and coach them on how to park better in the future GPS location technology with photo enforcement, to ensure devices are parked correctly in designated parking bays. Geo-fencing: GPS or RFID technology is used to create a virtual geographic boundary around an area, enabling software to trigger a notification when the device is parked outside the fenced area.	
Enabling technologies	Sensor technology, GPS, cameras, smartphone apps, RFID technology, software solutions	
Benefits	Increase e-scooter parking compliance by 35-97% Reduction in time spent looking for parking from 15 minutes down to 5 minutes Reduction of illegal parking by about 65%	
Maturity levels of technology	Moderate.	
Reliability	The market for smart parking is still in development. Early indications is that the solutions on offer are safe and reliable	
BCR	2.5-4.7	
Interoperability and maturity of standards	High.	
Countries	Spain, US, Russia, Australia	
Success factors	• Parking investment • Public acceptance • Require signage where parking is restricted, and use geofencing (as feasible) to reinforce restrictions in specific areas. • Require e-scooters to be parked upright; prohibit parking of e-scooters in or in front of pedestrian crossings and loading zones; and regulate parking of e-scooters on sidewalks to maintain Americans with Disabilities Act access, which may include directing e-scooter parking to corrals, parking racks, or other designated parking locations.	Shared mobility providers are generally responsible for the development of these technologies but they need to be supported by local governments and councils through stakeholder engagement and development of agile regulations and policies.

Active transport sector	Fleet management	
Description	This functional area includes digital solutions and technologies for real-time monitoring such as battery lifespan monitoring, alerts and system reporting, performance management and control, work hours monitoring, predictive maintenance and collision detection	
Example solutions	Key technologies already included in shared mobility devices including Lime, Neuron Mobility, Beam Mobility and other providers.	
Enabling technologies	Sensors, GPS, data analytics, hardware and software, IoT solutions, mobile apps, 3G and 4G connections, GSM and Bluetooth connectivity, infrared and ultrasonic sensors and devices, ML, and AI	
Benefits	Improved operations, better customer service and satisfaction and enhanced asset protection and maintenance.	
Maturity levels of technology	Moderate	
Reliability	Moderate. Reliance on GPS can impact performance particularly in areas with obstructions for longer periods of time such as in city centres where the reception may be weak.	
BCR	2.0-3.5	
Interoperability and maturity of standards	High	
Countries	UK, China, Norway, Switzerland, US, Germany, Canada	
Success factors	• Stakeholder consultations particularly involvement of key community groups • Provision of real-time data on shared-device locations • Set minimum fleet goals with incentives for underserved and/or lower-demand areas to ensure equitable distribution • Discounted fare programs and cash payment options for low-income users	Shared mobility providers are generally responsible for the development of these technologies but they need to be supported by local governments and councils through stakeholder engagement and development of agile regulations and policies.

Active transport sector	Travel experience	
Description	This functional area includes solutions to improve customer travel experience, safety and convenience such as pedestrian avoidance and lane detection technology; contactless payment solutions; and mobile apps for health monitoring	
Example solutions	Examples include advanced rider assistance technology (navigation system that allows riders to get from origin to destination without looking at their phone); geofencing requirements to prevent access to specific roadways, trails or geographic areas where the e-scooter would automatically slow down to walking pace to prevent irresponsible use and accidents in no riding zones or low speed zones	
Enabling technologies	Sensors, GPS, data analytics, hardware and software, IoT, mobile apps, 3G and 4G communications, Bluetooth connectivity, infrared and ultrasonic sensors and devices, computer vision technology, AI algorithms	
Benefits	Increased ridership, reduction in the time spent looking for a mobility device, automatic reduction of speeds at specified locations in low speed zones, improved safety and customer satisfaction	
Maturity levels of technology	Moderate	
Reliability	Moderate	
BCR	4.0	
Interoperability and maturity of standards	high	
Countries	Australia, Milan, Paris and Barcelona, US, New Zealand, Canada, Sweden, UK	
Success factors	• Encouragement and facilitation of trials • Ensuring private data protection • Investment in new technologies • Stakeholder consultations particularly involvement of key community groups	Shared mobility providers are generally responsible for the development of these technologies but they need to be supported by local governments and councils through stakeholder engagement and development of agile regulations and policies.

A summary of the benefit-to-cost ratios for digitisation of different functional areas covered in this section are presented in **Figure 10.**

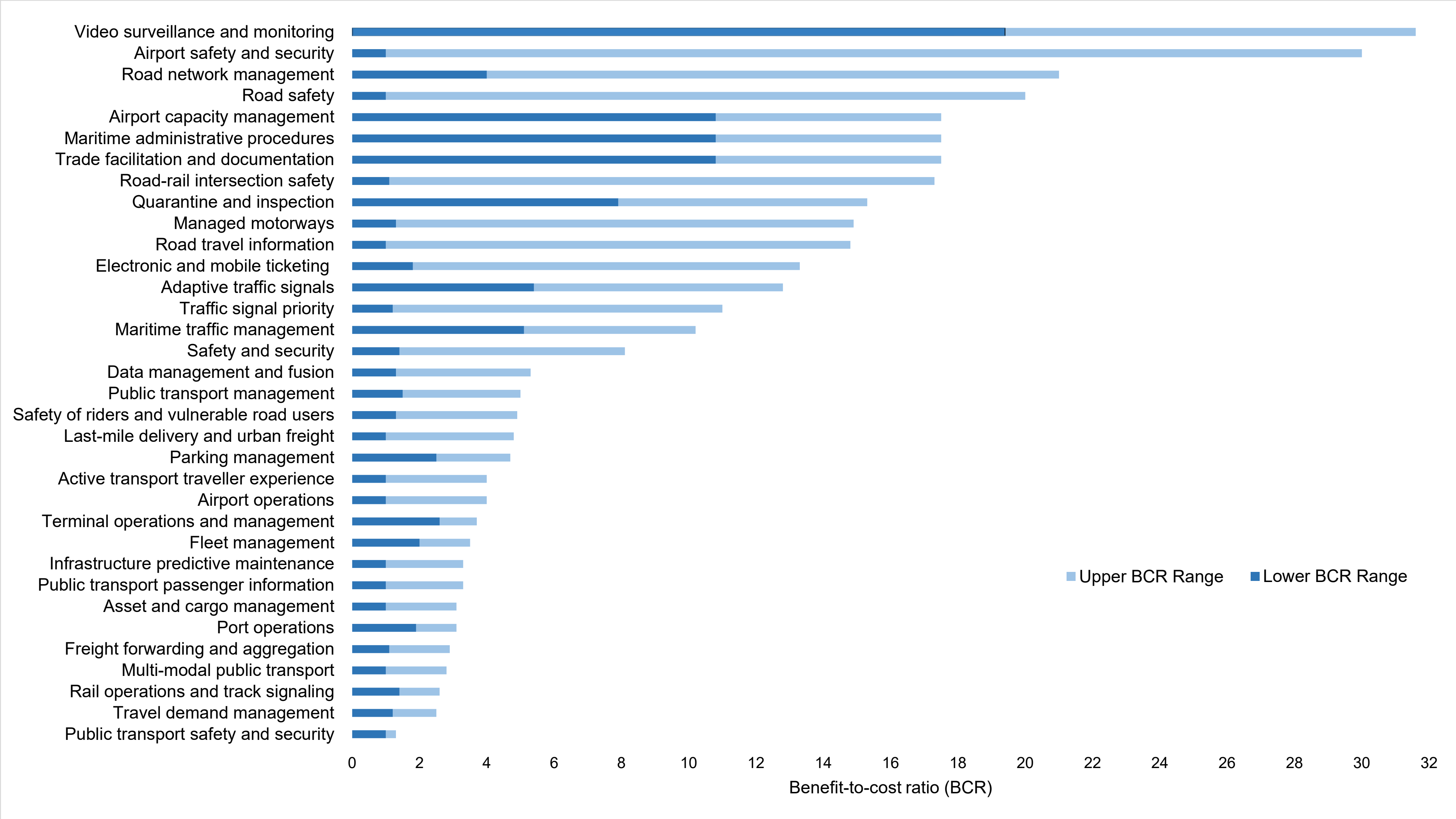


Figure 10: Average BCRs of transport digitisation

Road pricing: How Singapore harnessed tech-driven travel demand management

In this section of the report, we outline the case study of Singapore’s successful journey as the first nation to introduce and implement road network pricing as a form of travel demand management (congestion pricing). This case study is not articulated in detail as a recommendation, rather it is presented as an exemplar of one particular field of transport digitisation that involved extensive planning and stakeholder engagement to bring it to successful fruition. Similar success stories on road pricing have also been reported for London, Stockholm and Milan. The report appendix included a number of other successful transport and freight digitisation case studies.

In the context of travel demand management, road network pricing refers to wide-ranging strategies aimed at managing private vehicle travel, reducing road congestion and enhancing performance of the road network. These strategies are primarily aimed at managing travel demand on public roads by discouraging the use of low occupancy private vehicles, influencing travel behaviour, and shifting travellers away from private vehicles and towards more sustainable modes of transport. They are normally deployed at a number of spatial levels at a certain road facility, cordon or zone, or distance-based pricing. Similarly, they can be deployed at a number of temporal levels, including strategies for fixed pricing, time-of-day pricing or dynamic pricing. These strategies, when considered as part of a holistic approach, would result in positive impacts including reducing congestion and emissions as in the case of Singapore.

Singapore's initial congestion pricing scheme was established in 1975. Initially, it was known as area licensing scheme and was operated using a flat rate fee. The system was successful in reducing traffic congestion by 45% and vehicle crashes by 25%. The system was upgraded to ERP in 1998 resulting in a further 15% reduction in traffic congestion. More recently, the ERP was found to have reduced congestion by 45%, road crashes by 25%, as well as reduced traffic volumes entering the central business district by 15%.

Project snapshot

Year	Scheme development
1975	Area Licensing Scheme (ALS) operated from 7:30 am to 10:15 am Monday to Saturday
1985	Government considered ERP trial in Hong Kong, China
1989	ALS included evening peak hours from 4:30 pm to 7:00 pm from Monday to Friday. Government announced it will implement ERP
1990	The evening peak hours of ALS was extended to 6:30 p.m. Government studied electronic road toll systems in the US and Europe
1991	Government decided to use smart card system for ERP
1994	ALS operating hours were extended from 7:30 am to 6:30 pm. from Monday to Friday and 7:30 am to 3:00 pm on Saturdays.
1994	Under the modified scheme, motorists with part-day area license could enter the restricted zone between 10:15 am and 3:00 pm on Saturdays
1995	Interim RPS was implemented with operating hours from 7:30 am to 8:30 am on weekdays
1997	RPS covered Pan Island Expressway and Central Tunnel Expressway. Operating hours were from 7:30 am to 9:30 am
1998	ERP was launched. The system automated the manual road pricing system

Results

Singapore was able to ease traffic congestion in the city centre despite the continued growth in car population. Traffic volumes stayed below 1975 levels. Average speeds during peak hours stayed within the optimal speed range at 64.1 km/h for expressways and 28.9 km/h for arterial roads based on 2014 data. According to the latest household survey, the percentage of travellers using public transport during peak hours increased to 63% in 2012 from 59% in 2008, reversing the downward trend since the survey was first conducted in 1997 (ITDP, 2016).

The reduction in traffic volumes as a result of the Area Licensing Scheme from 1975 to 1998 is estimated to have resulted in about 1,907 kilotons in cumulative carbon dioxide emission reduction. The implementation of ERP from 1998 to 2008 is estimated to have reduced carbon dioxide emissions by 103 kilotons (ITDP, 2016).

Lessons

Building flexibility into the system

Congestion pricing schemes should be dynamic and allow rates to be adjusted according to actual traffic conditions. In Singapore, the congestion charge is lowered or raised when the average speed of vehicles exceed or fall behind the optimal speed range for the road. This is how it was possible to keep traffic below maximum capacity.

Institutions and stakeholders

Financing
Government of Singapore

Planning and design
Public Works Department
SingTel
National Computer Board

Executing agency
Land Transportation Authority

Developing a holistic transport strategy

ERP on its own is not a sufficient travel demand management policy. It needs to be integrated with other policy tools to manage traffic congestion and improve transport network efficiency. For example, Singapore limits vehicle ownership through a vehicle quota system and uses ERP to control vehicle usage. At the same time, it continues to invest heavily in improving the cost efficiency and convenience of public transport systems to move more people away from private transport.

Securing political and public support

The implementation of road pricing in Singapore required strong political will and public acceptance. The scheme was backed by the prime minister and a high-level transport committee. The government also carried out stakeholder consultations and outreach activities to explain the scheme to the public and get their feedback on the pricing structure. It also highlighted the scheme's benefits including faster travel times, increased economic opportunities, and improved quality of life. It also promoted the impact of complementary measures, such as improving public transport systems.

Improving the system to make it more equitable and efficient

Singapore has had to revise the scheme multiple times over the years to ensure that it achieved its objectives as traffic conditions changed. Developments in technology also made it possible to make the system more equitable and efficient. The government plans to upgrade the roadside gantry system to a GPS-based system, which will allow distance-based road pricing.

A number of other countries have followed Singapore's successful example and implemented various forms of congestion pricing. Cities where similar congestion pricing schemes are currently operating include London, Stockholm, Milan and Gothenburg.

The multiplier effects of digitisation

The review of case studies and lessons learned from individual case studies presented in this section also showed that countries with high levels of transport and freight digitisation were those who recognised the multiplier effects of digitalisation in different transport and freight sectors. Countries that recognised the importance of integrated digital systems and a holistic digital strategy were also rewarded with productivity gains through extracting maximum capacity from their existing transport and freight systems. While implementing these solutions may not always be as visible as celebrating new infrastructure expansion projects, funds invested on digitisation solutions have consistently outperformed productivity gains of other projects and delivered more benefits per dollar spent. When comparing different options, traditional capacity expansion projects (such as building new roads or tunnels), provided on average, a BCR of 3.0. This is much lower than the average BCR values of many technology and digitisation solutions that have been reported in the case studies presented before (**Figure 10**).

To demonstrate the value of the force multiplier when combining or deploying a number of solutions at the same time, the Florida Department of Transportation provides a good example. The department has been implementing a transport technology program on its networks for a large number of years. The solutions include incident management, ramp signalling, traveller information and express lanes (Dia, 2017). In 2018, the benefits of this program totalled almost US$3.1 billion (A$4.5 billion). The costs were US$70.3 million (A$102 million) resulting in a BCR of 43.7 as shown in **Figure 11**. In the UK, the cost of the technology solutions on the M42 motorway was US$150 million (A$218 million) and took two years to complete. Widening the road to produce the same outcome would have taken 10 years and cost US$800 million (A$1.16 billion) (Dia, 2017). Finally, technology is getting to the point today where it can making a significant difference in tackling the mega challenges facing our communities. Therefore, its role should be prioritised so that the benefits are realised sooner than later. These systems improve the use of existing assets and increase their operational life. They also enhance travel experience, reduce reliance on building new roads and deliver superior value for money.

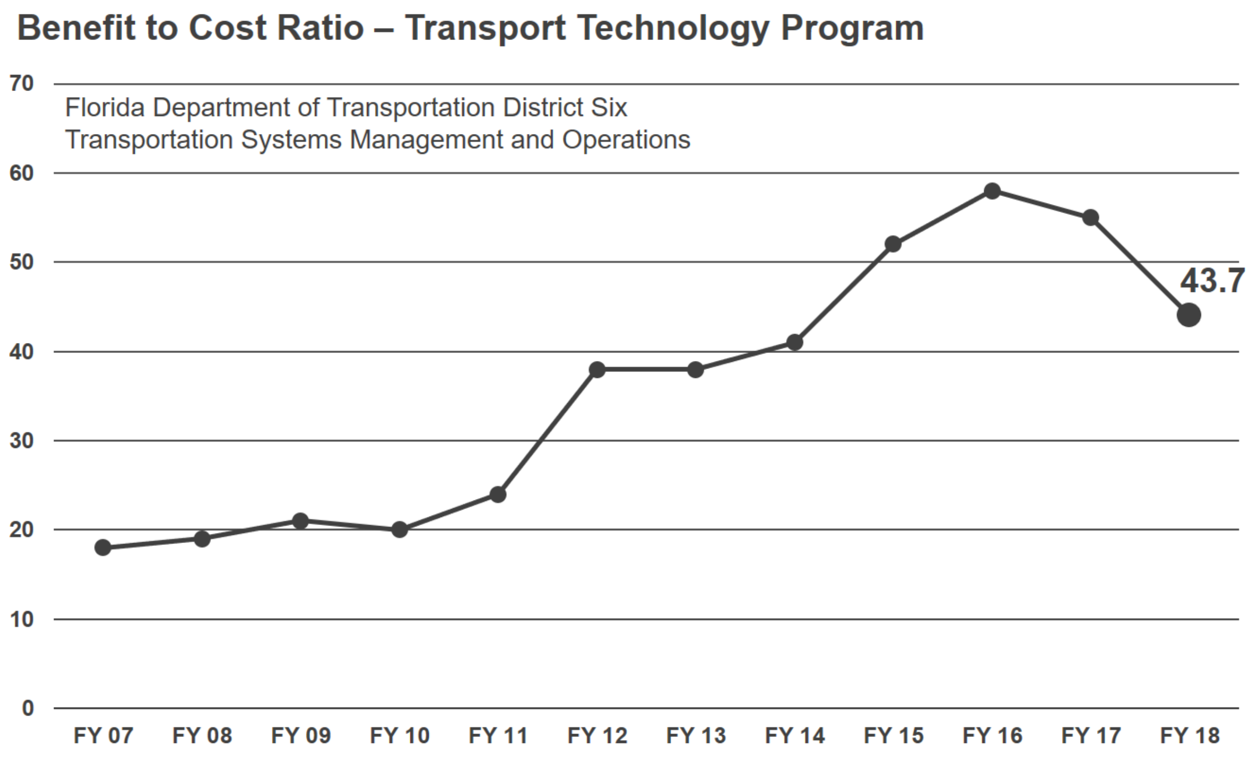


Figure 11: Benefit-cost ratio of transport technology program, Florida
Source: Authors

Impact of technology on freight and logistics services

Complex industrial supply chains encompass substantial movement of freight between different production, storage and distribution sites, which are typically undertaken by HVs (Ghaderi et al., 2016a). Any advances in technology that are beneficial for automated vehicles could also result in automated freight delivery, potentially saving significantly on the cost of operations by eliminating the need for driver labour when the system reaches full autonomous operations. Vehicle autonomy for the purpose of freight delivery can be loosely classified into autonomous driving, platooning and automated hand-to-hand delivery of goods to the end customer. The operations of these systems can be fully executed autonomously with all the mechanisms and intelligence on board of the vehicle, or in association with infrastructure, other vehicles or both (Bishop, 2000).

Autonomous technologies are already in commercialisation stages for land-based freight transport systems (Milakis et al., 2017). For instance, the Australian mining company Rio Tinto, ran its first fully autonomous bulk train in September 2017 by concluding a 100-kilometre pilot route with no operator on board, and currently, around 20% of all train activity are undertaken autonomously. The company is expanding its fleet of autonomous heavy haul trucks to 50% at its iron ore mining zone by retrofitting the vehicles with Autonomous Haulage Systems (RioTinto, 2017). The shipping industry is also experiencing a major progress in development of autonomous technologies for transport of passenger and freight, with many of these advancements promising economic benefits through removal of crew and safer navigation as the result of eliminating human error (Burmeister et al., 2014; Ghaderi, 2019; Kretschmann et al., 2017). As the world's first autonomous container vessel, YARA Birkeland will be fully electric with flexible manoeuvring and propulsion system. As a zero-emission vessel, it will remove around 40,000 diesel-powered truck haulages annually, which translates into a substantial reduction of noise and dust, improved safety of local roads and reduction in emissions (Yara, 2017).

Over the last two decades, truck automation has demonstrated the potential to bring major improvements to the problems of traffic, supply chain costs and emissions (Bengler et al., 2014). One of the major innovations in freight vehicle automation is truck platooning (Tsugawa et al., 2016). Platooning is an extension of adaptive cruise control, in which at least two vehicles travel in a convoy, using real-time connectivity technology and automated driving support systems (Poorsartep and Stephens, 2015). Due to reduced air resistance, truck platooning promises reduced fuel consumption when vehicles are coupled in road train platoons (Janssen et al., 2015). Truck platooning is also considered to be a potential solution to mitigate some of common supply chain problems caused by human driver inefficiency and network congestion (Saeednia and Menendez, 2017). Given the rising operational costs and the emergence of automated and connected technologies, truck platooning is now seen as the next technological step towards improved freight transport (Zijm and Klumpp, 2017). For example, Scania is developing a full-scale autonomous truck platooning system, to move containers between port terminals in Singapore (Scania, 2018). The objective is to operate convoys of four trucks in a platoon following the lead autonomous truck, as well as automating docking and undocking of cargo in port areas. Given the complex challenges associated with congestion and increasing port-related freight movement (Ghaderi et al., 2016b; Jeevan et al., 2015), this program is instrumental for better optimisation of traffic flow in Singapore.

Growth in B2B and B2C services has increased the demand for light vehicles for delivery of goods particularly in urban areas (Allen et al., 2018). For businesses involved in distribution of consumer goods, solving the last kilometre problem is a significant challenge (Hsiao et al., 2018). Managing the last kilometre delivery in a cost-effective approach is a complex task due to low volume and diverse nature of distribution tasks (Pronello et al., 2017; Soleimani et al., 2018). The cost of last kilometre delivery is significant and could exceed 50% of the total transport expenses. Despite numerous benefits of autonomous vehicles, the challenges associated with delivery of freight in urban areas are more diverse and complex compared to long haul transport (Lim et al., 2018; Morganti et al., 2014). Given this challenge, a number of companies, including car manufacturers, tech-based start-ups and courier services are now exploring the opportunities for employing autonomous vehicles for last kilometre delivery as a rewarding value proposition. Uber for example, is reported to be conducting research to enable its future fleet of autonomous vehicles to deliver small parcels. Other companies are also evaluating disruptive business models in the last kilometre delivery space such as Amazon's Prime Air delivery drone. Therefore, effective incorporation of autonomous vehicles into urban freight supply chains will be a game changer for businesses in search of building a competitive advantage in the city logistics and e-fulfilment space (Fagnant and Kockelman, 2015).

Another area in which autonomous vehicles could potentially play a role is in reverse and green supply chains. With the increasing concerns around environmental impacts of consumer goods, many businesses are investing in greener supply chains in which materials are repaired, re-used, re-manufactured and recycled in a more cost-effective and sustainable manner (Zarbakhshnia et al., 2018; Zakharenko, 2016). However, several challenges currently impede the success of these solutions. In particular, recycled materials have lower value, and thus, in many cases the distribution and collection costs don't offset the recycled value. The incorporation of autonomous vehicles into reverse supply chains create enormous opportunities by reducing the logistical costs associated with collection of such materials.

Comparative evaluations

Comparative evaluations based on international indicators

This research uses available international indicators, informed by the findings from this study related to the productivity potential of each functional area, to develop a best practice transport and freight digitisation composite indices for benchmarking the performance of OECD countries in transport and freight digitisation. The indices are based on three digitisation-related pillars that include productivity, industry/consumer acceptance, and policy and regulations. As part of this study, a research tool is being developed to evaluate the importance of each of these indices in describing the best practice transport and freight digitisation index, and its sensitivity to each component.

The study considered a large number of available indices, but only used those that are widely accepted in global comparative evaluations and are acknowledged as reliable indicators particularly for OECD countries. In the next section, we present each of the indices used and highlight their limitations.

Productivity pillar

This pillar includes a number of country indicators relevant to the role of digitisation in improving productivity. It considers indicators that cover best practice digitisation in transport and freight in terms of the level of technology sophistication and scale up. It also considers a number of other information and communication technology indicators that reflect the extent of a country’s digitisation and the role it plays in enabling a technology-driven ecosystem that supports innovation and pathways to digitisation of various sectors in the economy.

Digitisation and prosperity index

The digitisation and prosperity index measures the extent of a country's digitalisation by using six key attributes: Ubiquity (the level of access to digital services and applications), affordability (pricing), reliability (the quality of connection), speed (the rate of data throughput), usability (the ease with which people can get online and use applications available there), and skill (the ability of users to incorporate digital services into their lives and businesses).

This index has a number of limitations including lack of data. Where accurate data was not available, proxy measures are used. For example, overall investment in the telecommunications sector was used as a proxy to measure the reliability of the underlying network. Similarly, a total of eight metrics were used to estimate network usability instead of actual data on number of connections, households and businesses online. In other instances, regression models were used to compensate missing data and observations.

https://www.strategyand.pwc.com/m1/en/reports/maximizing-impact-digitization.html

Global connectivity index

The global connectivity index is based on 40 ICT indicators that cover AI, IoT, Cloud, Broadband and fundamental ICT services across four pillars. The pillars include supply (measures current levels of supply for ICT products and services used for digital transformation); demand (gauges demand connectivity in the context of users and activities relating to digital transformation initiatives); experience (comprises variables for analysing the experience of connectivity for end-users and organisations in today's digital economy); and potential (comprises a forward-looking set of indicators that point towards the future development of the digital economy).

This index has a number of limitations including the data currency and consistency of the sub-indices and other information used in its development. A number of measures are also used to compensate for missing data including estimations based on trends within geographical cohorts.

https://www.huawei.com/minisite/gci/en/index.html

Network connectivity testing index (two indices for mobile and broadband)

Network connectivity testing index compares mobile and fixed broadband internet speed data from countries around the world on a monthly basis. Data for the index is derived from the hundreds of millions of tests taken by people using the 'speed test' tool every month. Each time a test is initiated, a snapshot of what the internet looks like in a certain location is recorded. When locations across a country or geographical area are aggregated, these individual experiences collectively represent the typical internet performance for a given country. For example, the August 2021 index showed that maximum broadband download speeds were 262.2 megabits per second (Mbps) in Singapore, compared to 164.16 in New Zealand, 85.57 in Australia, 62.45 in India, and 26.95 in Indonesia.

https://www.speedtest.net/global-index

The broadband network connectivity testing index, in particular, has a number of limitations. First, it does not provide for like-to-like comparisons between countries in terms of income, geography and population density. Second, the index compares countries based on tests of 'average experienced download speed'. These speed tests have a number of limitations that affect how they are measured and interpreted and depend on factors such as congestion, the speed of a user's broadband subscription plan and the technical configuration of the test itself. The speed is also impacted by data collection factors such as the time and frequency of measurement, location of measurement, how the user has configured their access to the network, and how the measurement itself has been designed. Cross-country comparisons can also be limited by sampling differences, such as the size and cohort of users sampled in broadband performance measures. For example, in some countries there are several million speed tests conducted every month, whereas in other countries there may only be a few hundred speed tests conducted over the same period. Further, some speed tests allow the inclusion of results even from quite small samples. This means the results are not able to be compared consistently as smaller sample sizes are less likely to be representative of whole-of-country results. Third, speed alone is not a sufficiently useful measure to assess fixed broadband performance. Experienced speed measures, on their own, have limited relevance for understanding and assessing fixed broadband performance. Other elements of broadband performance include the speeds users subscribe to, network coverage, uptake of broadband services, network congestion at the test time and the quality of in-home networks. Despite these limitations, the broadband network connectivity index has been widely used in global comparative evaluation studies and is particularly useful for observing and comparing trends between years for all countries in the index. In this study, it is used as one of 10 global indicators.

In response to these limitations, the Bureau of Communications, Arts and Regional Research (BCARR) proposed a number of other measures for evaluating broadband performance and user experience (DITRDC, 2020). These include coverage and accessibility (evaluates opportunity to access the benefits facilitated by broadband); minimum speed (measures whether overall user experience is improving); uptake of higher speed plans (evaluates whether citizens are aware of the social and economic benefits of fixed broadband); and data consumption (measures extent to which citizens are realising the benefits of fixed broadband). The BCARR measures, however, included only a subset of the OECD countries considered in this research and it was hence difficult to include them in this analysis because of a substantial amount of missing data for other countries. According to the BCARR measures, Australia ranked first out of 15 countries in terms of percentage of households with access to fixed broadband speeds of at least 25-30 Mbps. Australia also ranked 8 of out 17 countries in terms of overall percentage of households able to access fixed broadband. The BCARR measures also showed that Australia ranked , 10 out of 16 countries in terms of household broadband speeds greater than or equal to 100 Mbps.

IMD world digital competitiveness ranking index

This index measures the capacity and readiness of 63 economies to adopt and explore digital technologies for economic and social transformation. The ranking relies on three factors: (i) knowledge, which captures the intangible infrastructure necessary for the learning and discovery dimensions of technology; (ii) technology, which quantifies the landscape of developing digital technologies; and (iii) future readiness, which examines the level of preparedness of an economy to assume its digital transformation. One of the key assumptions in this index is that digital transformation takes place primarily at enterprise level (whether private or state-owned) but it also occurs at the government and society levels.

https://www.imd.org/centers/world-competitiveness-center/rankings/world-digital-competitiveness/

The global innovation index

This index ranks 132 world economies, which represent around 94% of the world's population and 99% of the world's GDP, according to their innovation capabilities. The index includes 81 indicators and relies on two sub-indices which comprise the innovation input sub-index and the innovation output sub-index. The innovation input sub-index includes five pillars that capture elements of the economy which enable and facilitate innovative activities. The innovation output sub-index includes two pillars which represent outputs resulting from innovative activities within the economy. The overall global innovation score is then calculated as the average of the input and output sub-indices, on which the economy rankings are then produced. This index presents a scoreboard for each economy that includes strengths and weaknesses.

This index has a number of limitations particularly extent of missing data for the 81 indicators for some of in the emerging economies outside the OECD. However, the index has robust methodologies in place for handling missing values which are excluded in the sub-pillar scores. Also, changes to economies selection influence the year-on-year comparisons of rankings. For example, nine economies were no longer considered innovation achievers in 2021, relative to 2020. Another limitation is that potentially problematic indicators with outliers are included, which could polarise results and unduly bias the rankings.

https://www.globalinnovationindex.org/analysis-indicator/

Industry and consumer acceptance pillar

Network readiness index

The network readiness index measures how well technology and people are integrated within an effective governance structure that facilitates positive impact on economy, society and the environment. It also provides an assessment of the impact of ICT on the competitiveness and wellbeing of countries by measuring the propensity for countries to exploit the opportunities offered by ICT. The index ranks 134 economies based on their performance across 60 variables and includes four fundamental dimensions: (i) technology (assesses the level of technology essential for a country's participation in the global economy with sub-pillars that include access, content and future technologies); (ii) people (applications of information technology by people at three levels of analysis that include individuals, businesses, and governments); (iii) governance (captures how conducive the national environment is for a country's participation in the network economy, based on trust, regulation, and inclusion); and (iv) impact (assesses the economic, social, and human impact of participation in the network economy including quality of life and the UN Sustainable Development Goals).

This index has a number of limitations mainly related to lack of data and treatment of missing information or outliers. Due to lack of data, the index includes only countries with data available for at least 70% of indicators used in its development. In this index, missing values are not taken into account in the computation of scores. The data used in estimation of this index also included at least five outliers for more than six indicators. The presence of outliers in an indicator can potentially bias rankings.

https://networkreadinessindex.org/

Policy and regulations pillar

Global competitiveness index

The global competitiveness index (GCI), compiled by the World Economic Forum, measures the ability of countries to provide high levels of prosperity to their citizens. It also assesses how productively a country uses its available resources, and the set of institutions, policies, and factors that set current and medium-term levels of economic prosperity. The index is comprised of 12 categories that include institutions, infrastructure, ICT adoption, macroeconomic stability, health, skills, product market, labour market, financial system, market size, business dynamism and innovation capability. It is generally used to assess the future orientation of government and role of their policies and regulations in overcoming barriers to innovations.

This index has a number of limitations mainly related to exclusion of ecological footprints, lack of independence between the indicators used under each category; and weightings used for each category. For example, none of the indicators used to determine this report's competitiveness ranking reflect any of the countries' environmental dimensions such as energy, water, climate risks, resource or food security. In cases were the ecological footprint was used as a context indicator, it was not included in the scoring algorithm that determines the ranking. Although results are reported for the 12 categories of competitiveness separately, they are not independent. This presents issues because dependent indicators tend to reinforce each other, and a weakness in one often has a negative impact in others. Finally, assumptions are made in this index about the weights assigned for each category to reflect the relative influence they could have on different economies.

https://www.weforum.org/reports/the-global-competitiveness-report-2020

International change readiness index

The international change readiness index, compiled by KPMG, is a measure of government readiness for change. It indicates the capability of a country, its government, private and public enterprises, people and broader civil society, to anticipate, prepare for, manage, and respond to a wide range of change drivers. Examples of change include opportunities and risks of technology, competition, changes in government, shocks such as financial and social instability and natural disasters. The international change readiness index comprises three interrelated pillars: government; enterprise; and people and civil society. The index is generally used to improve government policy by benchmarking national strengths and weaknesses and identifying areas in need of reform, building best practice by stimulating debate on change readiness and learning from higher-ranking countries, and identifying potential public and private sector partnerships by identifying areas to match capabilities and resources with highest priority needs.

The index uses equally-weighted pillar scores derived from standardised sub-index scores that are in turn derived from standardised primary survey question responses and secondary data. This methodology introduces a number of limitations mainly related to the quality of data used for each sub-index.

https://home.kpmg/xx/en/home/insights/2019/06/2019-change-readiness-index.html

Open data barometer

The open data barometer index, compiled by the World Wide Web Foundation, measures the prevalence and impact of open data initiatives around the world. It analyses global trends and provides comparative data on governments and regions using a methodology that combines contextual data, technical assessments and secondary indicators. This index is based on three components that cover (i) readiness for open data initiatives (e.g. policies, government action, entrepreneurs and business, citizens and civil society); (ii) implementation of open data programs (e.g. accountability, innovation and social policy); and (iii) the impact of open data (business, economic, political and social). This index is limited by country coverage. The index includes only 30 governments that have made commitments to champion open data, either by adopting the Open Data Charter or by agreeing to the G20 Anti-Corruption Open Data Principles.

https://opendatabarometer.org/4thedition/?_year=2016&indicator=ODB

Note on investment pillar

A fourth pillar, transport infrastructure investment as share of GDP, was initially proposed but after some analysis we will no longer use it due to key limitations. This indicator, compiled by the OECD, measures each country's transport infrastructure investment as share of its GDP for the total transport inland investment. It also measures investment in Euros for the individual road, rail, air, inland waterways and sea components. The appeal of this indicator was its potential to reflect how investment in transport infrastructure can reduce congestion, improve road safety and connectivity. After careful consideration, it became apparent that a key limitation of this index is that the cost of construction in some countries like Australia, New Zealand, UK and the US is much higher than OECD average. The higher expenditures were found to be a result of cost overruns as opposed to rolling out more kilometres of transport infrastructure that could lead to improvements in productivity. Hence, its use will likely skew results in favour of countries that have higher construction costs compared to OECD countries. Also, the ideal relevant indicator to use in this study to represent investment would have been the transport technology investment as share of GDP, but this information is not available and remains a data gap.

Given these limitations, the OECD infrastructure investment indicator will be excluded from the analysis.

https://data.oecd.org/transport/infrastructure-investment.htm#indicator-chart

OECD country digitisation scores

Table 4 presents the OECD country digitisation scores and rankings based on the following 10 international indicators:

1. Digitisation and prosperity index
2. Global connectivity index
3. Network connectivity testing index (mobile)
4. Network connectivity testing index (broadband)
5. Network readiness index
6. GCI
7. International change readiness index
8. Open data barometer
9. IMD world digital competitiveness ranking index
10. The global innovation index

This information is used then used to calculate an average country digitisation score based on equal weightings for each of the 10 scores as shown in the table.

Table 4: OECD country scores based on selected international digitisation indices

OECD country	Digitisation and Prosperity Index	Global Connectivity Index	Network Connectivity Index (Mobile)	Network Connectivity Index (Fixed Broadband)	Network readiness index	Global Competitiveness Index	International Change Readiness Index	Open Data Barometer index	IMD World Digital Competitiveness Index	Global Innovation Index	Average Index	Rank
Switzerland	55.0	81.0	56.0	100.0	80.4	82.3	100.0	57.0	94.9	65.5	77.2	1
Denmark	55.0	77.0	48.8	96.9	82.2	81.2	85.3	71.0	95.2	57.3	75.0	2
Korea	55.0	71.0	100.0	97.1	74.6	79.6	38.2	81.0	89.7	59.3	74.6	3
United States	55.0	87.0	44.8	87.7	78.9	83.7	64.7	82.0	100.0	61.3	74.5	4
Norway	55.0	73.0	89.3	67.7	79.4	78.1	79.4	74.0	91.3	50.4	73.8	5
Sweden	55.0	80.0	45.2	70.7	82.8	81.2	85.3	70.0	95.2	63.1	72.8	6
Netherlands	55.0	75.0	47.2	67.8	81.4	82.4	76.5	75.0	93.3	58.6	71.2	7
Canada	55.0	70.0	39.8	75.6	74.9	79.6	64.7	90.0	87.3	53.1	69.0	8
United Kingdom	55.0	75.0	35.8	32.5	76.3	81.2	76.5	100.0	85.8	59.8	67.8	9
France	55.0	70.0	31.0	89.1	73.2	78.8	50.0	85.0	75.7	55.0	66.3	10
Finland	55.0	76.0	37.1	51.3	80.2	80.2	73.5	56.0	90.1	58.4	65.8	11
New Zealand	55.0	72.0	31.4	69.1	73.3	76.7	76.5	79.0	77.1	47.5	65.8	12
Germany	55.0	70.0	32.9	51.2	77.5	81.8	79.4	70.0	79.3	57.3	65.4	13
Japan	55.0	75.0	24.6	77.7	73.5	82.3	55.9	75.0	73.0	54.5	64.7	14
Australia	55.0	72.0	62.4	27.0	75.1	78.7	64.7	81.0	78.7	48.3	64.3	15
Luxembourg	55.0	70.0	53.0	73.9	75.3	77.0	56.2	35.0	77.4	49.0	62.2	16
Iceland	55.0	66.2	34.3	57.7	70.6	74.7	65.1	39.0	77.6	51.8	59.2	17
Austria	55.0	66.0	27.5	31.4	72.9	76.6	55.9	70.0	80.9	50.9	58.7	18
Spain	55.0	61.0	17.0	81.5	67.3	75.3	29.4	73.0	68.2	45.4	57.3	19
Israel	55.0	65.4	15.8	69.1	69.8	76.7	41.2	46.0	79.6	53.4	57.2	20
Belgium	55.0	66.0	29.7	46.4	70.7	76.4	52.9	45.0	75.3	49.2	56.7	21
Ireland	55.0	69.0	21.2	44.1	72.1	75.1	50.0	47.0	79.2	50.7	56.3	22
Slovenia	55.0	56.0	22.4	41.0	66.6	70.2	43.4	47.0	65.0	44.1	51.1	23
Portugal	55.0	61.0	14.3	59.3	64.4	70.4	32.4	42.0	65.2	44.2	50.8	24
Estonia	35.0	61.0	29.8	25.6	70.3	70.9	52.9	36.0	75.4	49.9	50.7	25
Lithuania	55.0	58.0	25.6	53.8	64.7	68.4	32.4	30.0	70.3	39.9	49.8	26
Czech Republic	55.0	57.0	22.9	27.4	66.3	70.9	38.2	44.0	65.2	49.0	49.6	27
Italy	55.0	60.0	16.6	31.7	63.7	71.5	29.4	56.0	61.8	45.7	49.1	28
Poland	55.0	51.0	19.4	60.1	61.8	68.9	29.4	34.0	60.9	39.9	48.0	29
Hungary	55.0	54.0	23.2	89.1	60.1	65.1	11.8	23.0	55.2	42.7	47.9	30
Chile	35.0	54.0	1.5	93.5	54.1	70.5	23.5	47.0	61.8	35.1	47.6	31
Slovak Republic	55.0	54.0	18.9	38.0	60.8	66.8	26.5	45.0	54.2	40.2	45.9	32
Latvia	35.0	55.2	15.3	52.9	60.5	67.0	35.3	28.0	63.9	40.0	45.3	33
Greece	55.0	52.0	30.0	0.0	55.2	62.6	2.9	39.0	55.6	36.3	38.9	34
Costa Rica	27.5	46.1	9.1	11.9	52.2	62.0	32.4	37.2	74.0	34.5	38.7	35
Mexico	35.0	43.0	9.1	9.6	49.7	64.9	0.0	73.0	48.7	34.5	36.8	36
Turkey	35.0	46.0	16.6	3.0	51.2	62.1	8.8	37.0	52.8	38.3	35.1	37
Colombia	35.0	42.0	0.0	17.9	46.8	62.7	0.0	62.4	45.5	31.7	34.4	38

Best practice transport and freight digitisation indices

In the next sections of the report, best practice transport and freight digitisation indices are developed and presented for each sector. The development of these indices was informed by data collected from a large number of sources that reflected each country's adoption of transport and freight digitisation, the degree to which their technology solutions reflected best practice, and the scale and prevalence of technology use. The information was sourced using the following methods:

1. Review of technical literature
2. Review of case studies and productivity indicators including BCRs
3. Annual reports of transport agencies (e.g. Florida Department of Transportation)
4. Government agencies, non-profit and peak-body websites (e.g. ITF, UITP, UN, World Bank)
5. International indices specific to each functional area (these are detailed for each sector in the following pages)
6. Scale of deployment within each country
7. Degree of sophistication and advancement of technology and digitisation solutions
8. Information collected from OECD and other publicly available databases

In cases where data was missing, the most suitable and relevant data imputation techniques were used including linear and polynomial regression.

In the following sections, best practice transport and freight diagrams are presented for OECD countries according to regional groups which include Asia Pacific (Australia, Japan, Korea and New Zealand), Europe and West Asia, America and Latin America

Road sector digitisation best practice index

The road sector digitisation best practice index is presented in **Figure 12** and **Table 5**. The indices reported for individual functional areas were estimated based on information documented in international case studies, government and industry reports and publicly available information on the relative performance of OECD countries for each functional area under the road sector.

The development and estimation of these indices was also informed by publicly available indicators including:

- Road connectivity index (link)
- Quality of road infrastructure index (link)
- Quality of railroad infrastructure index (link)
- Smart city index (link)
- The world's safest roads index (link)
- TomTom traffic Index 2020 (link)

Figure 12 is a representation of the road index using a radar diagram. The diagram shows a list of the OECD countries around the perimeter and plots the corresponding road index against each country. One of the advantages of this diagram is that it provides a visual representation of the degree of uniformity of best practice in these countries. A smoother plot or circle represents more uniform best practices. Amongst all sector indices, the road sector was found to have experienced most development in terms of digitisation and will be used in the diagrams as a comparator to developments in other sectors.

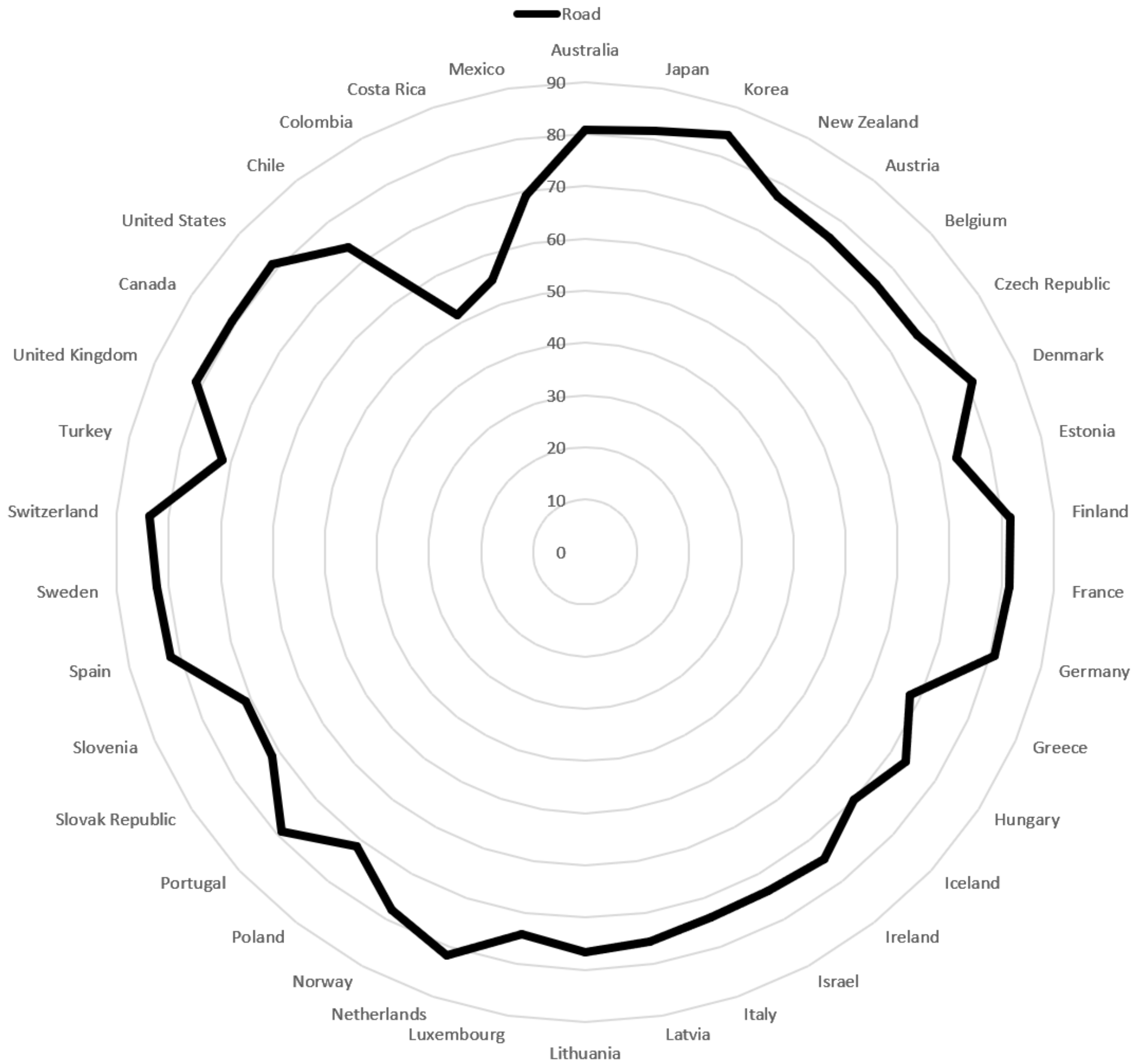


Figure 12: Road sector digitisation best practice index – regional grouping

Table 5: Road sector digitisation best practice index

OECD country	Road safety	Road-rail intersection safety	Adaptive traffic signals	Traffic signal priority	Network management	Managed motorways	Travel information	Demand management	Country digitisation index score	Road digitisation index score	Road digitisation index ranking
BCR	1.0-20.0	1.1-17.3	5.4-12.8	1.16-11.0	4.0-21.0	1.3-14.9	1.0-14.8	1.2-2.5			
Australia	84	78	86	88	80	88	80	80	64.3	80.9	12
Austria	76	76	80	82	81	81	75	75	58.7	76.2	19
Belgium	88	75	81	88	73	73	73	75	56.7	75.7	21
Canada	83	77	88	88	82	82	79	80	69.0	80.8	14
Chile	80	69	82	80	78	70	76	82	47.6	73.9	26
Colombia	60	45	56	52	51	51	60	56	34.4	51.7	38
Costa Rica	58	62	63	50	48	48	63	63	38.7	55.0	37
Czech Republic	83	77	87	85	74	74	73	82	49.6	76.0	20
Denmark	87	75	84	87	82	85	74	80	75.0	81.0	11
Estonia	83	70	81	87	74	74	62	80	50.7	73.5	28
Finland	80	79	88	88	83	85	77	88	65.8	81.5	7
France	80	77	88	88	83	85	78	88	66.3	81.5	8
Germany	81	78	87	88	82	85	77	85	65.4	80.9	13
Greece	67	62	74	76	70	80	70	75	38.9	67.9	36
Hungary	82	73	80	86	70	70	73	80	47.9	73.4	29
Iceland	80	68	71	70	65	70	71	75	59.2	69.9	34
Ireland	80	70	79	88	71	75	70	81	56.3	74.5	23
Israel	81	72	76	88	72	72	70	76	57.2	73.7	27
Italy	78	68	82	86	74	75	72	82	49.1	74.0	25
Japan	80	85	85	80	80	88	88	86	64.7	81.8	5
Korea	82	80	88	88	86	88	84	89	74.6	84.4	1
Latvia	81	76	84	88	70	70	84	84	45.3	75.7	22
Lithuania	80	75	82	88	76	76	82	82	49.8	76.7	18
Luxembourg	82	70	73	80	74	80	73	73	62.2	74.1	24
Mexico	74	65	77	78	71	70	74	77	36.8	69.2	35
Netherlands	82	79	86	88	87	88	74	80	71.2	81.7	6
New Zealand	82	68	79	88	72	85	73	84	65.8	77.4	17
Norway	88	71	76	88	70	88	69	76	73.8	77.8	16
Poland	80	71	80	85	72	72	71	63	48.0	71.3	32
Portugal	80	73	85	88	87	87	76	85	50.8	79.0	15
Slovak Republic	80	70	79	84	69	69	69	79	45.9	71.7	30
Slovenia	70	60	79	74	74	74	79	79	51.1	71.1	33
Spain	85	83	87	85	88	85	83	85	57.3	82.0	4
Sweden	87	82	85	88	84	84	77	82	72.8	82.4	3
Switzerland	88	83	80	88	83	85	85	85	77.2	83.8	2
Turkey	73	65	80	80	76	76	80	80	35.1	71.7	31
United Kingdom	84	73	85	88	80	88	82	84	67.8	81.3	10
United States	82	78	82	82	85	85	82	82	74.5	81.4	9

Legend										
More than 85	80-85	75-80	70-75	65-70	60-65	55-60	50-55	40-50	40-45	Less than 40
Best Practice					Moderate					Low

Public transport digitisation best practice index

The public transport digitisation best practice index is presented in **Figure 13** and **Table 6**. For public transport, the indices reported for individual functional areas were also estimated based on information documented in international case studies and from government and industry reports, including publicly available information on the relative performance of OECD countries for each functional area under public transport.

The development and estimation of these indices was also informed by publicly available indicators including:

- Ease of doing digital business index (link)
- Government e-payments adoption index (link)
- Smart city index (link)
- Deloitte city mobility index (link)
- Public transport systems city index (link)
- Urban mobility readiness index (link)
- Government surveillance and security index (link)
- OECD Open, useful and re-usable data (OURdata) index (link)
  Government AI readiness index (link)

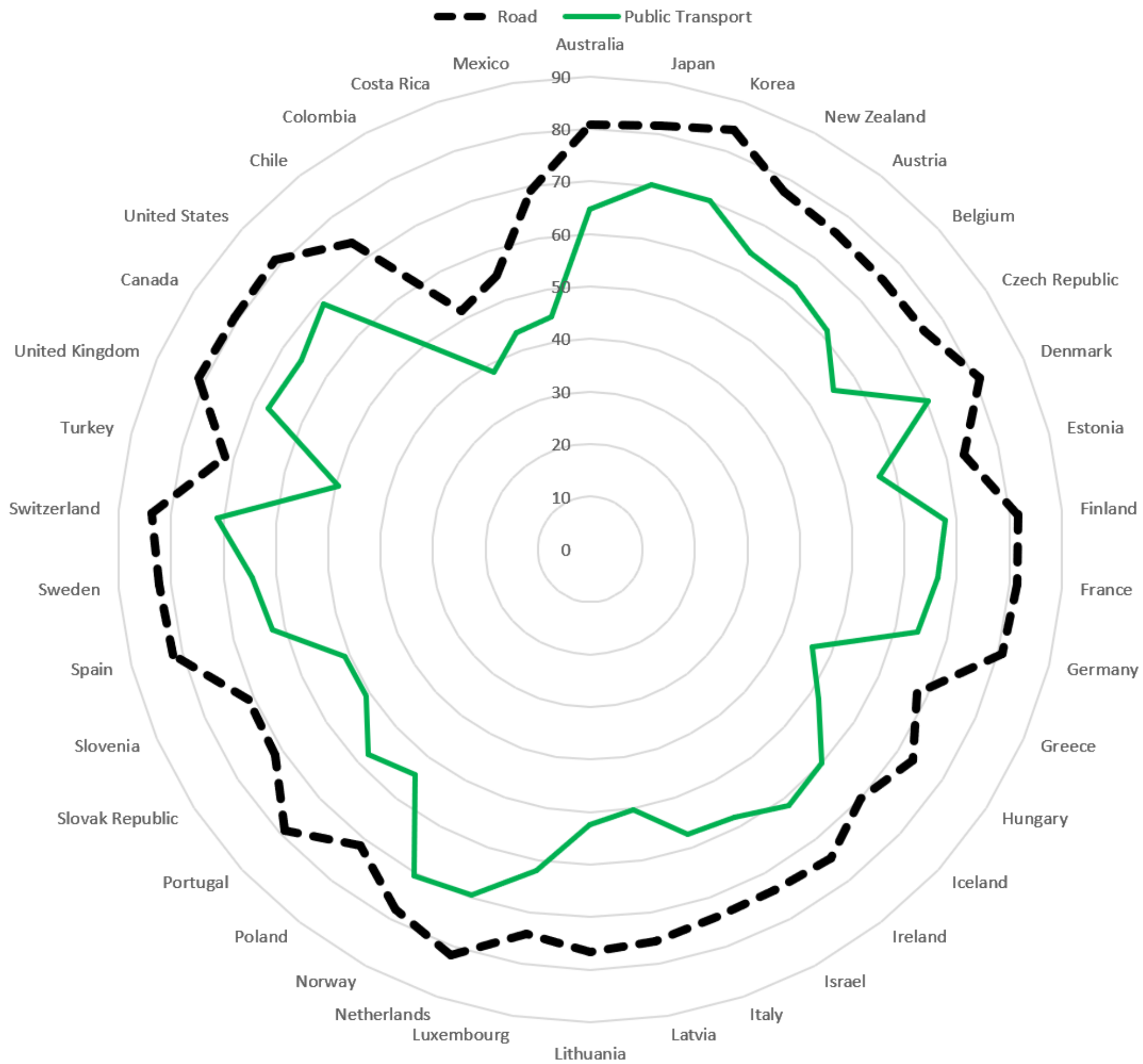


Figure 13: Public transport digitisation best practice index – regional grouping

Table 6: Public transport digitisation best practice index

OECD country	Safety, security and enforcement	Video surveillance and monitoring	Electronic and mobile ticketing	Passenger information systems	Personalised public transport	Multi-modal public transport	Public transport management	Data management and fusion	Country digitisation index score	Public transport digitisation index score	Public transport digitisation index ranking
BCR	1.0-1.3	19.4-31.6	1.8-13.3	1.0-3.3	TBC	1.0-2.8	1.5-5.0	1.3-5.3			
Australia	60	65	74	60	60	63	60	77	64.3	64.8	12
Austria	60	62	77	71	53	59	59	70	58.7	63.3	16
Belgium	80	60	61	52	43	80	57	63	56.7	61.4	20
Canada	80	60	73	58	54	68	51	80	69.0	65.6	11
Chile	48	48	66	36	46	48	48	51	47.6	48.6	33
Colombia	34	34	64	12	34	38	34	59	34.4	38.3	37
Costa Rica	39	39	69	39	39	39	39	52	38.7	43.5	36
Czech Republic	50	62	73	58	43	50	50	64	49.6	55.3	25
Denmark	75	63	81	59	62	75	75	68	75.0	70.3	4
Estonia	51	58	76	61	53	51	51	60	50.7	56.8	24
Finland	66	55	83	76	65	72	61	67	65.8	67.8	8
France	66	62	75	66	48	72	54	88	66.3	66.3	10
Germany	65	62	76	65	45	72	58	69	65.4	64.3	14
Greece	39	59	62	34	40	39	39	64	38.9	46.0	34
Hungary	48	55	76	47	40	48	48	58	47.9	52.0	28
Iceland	60	60	65	70	60	40	70	56	59.2	60.0	21
Ireland	80	65	71	49	54	60	48	71	56.3	61.7	19
Israel	57	60	65	45	56	57	57	66	57.2	57.9	21
Italy	60	58	70	52	41	69	49	68	49.1	57.3	23
Japan	100	58	67	96	30	76	62	80	64.7	70.4	3
Korea	75	75	80	81	39	68	59	81	74.6	70.2	5
Latvia	45	61	45	60	45	45	45	60	45.3	50.3	31
Lithuania	50	64	50	60	50	50	50	49	49.8	52.3	27
Luxembourg	62	57	62	66	62	62	62	61	62.2	62.0	18
Mexico	37	37	61	38	44	44	37	69	36.8	44.8	35
Netherlands	71	63	72	79	67	67	65	71	71.2	69.5	6
New Zealand	66	60	76	49	57	66	66	72	65.8	64.1	15
Norway	74	62	83	58	65	74	74	72	73.8	70.5	2
Poland	48	61	73	48	44	55	46	66	48.0	54.3	26
Portugal	60	63	64	54	56	60	51	59	50.8	57.5	22
Slovak Republic	46	59	71	50	41	46	46	54	45.9	51.0	29
Slovenia	51	52	51	36	51	51	51	65	51.1	51.0	30
Spain	60	62	72	73	50	63	57	67	57.3	62.3	17
Sweden	60	57	79	49	51	77	73	62	72.8	64.5	13
Switzerland	77	63	76	91	53	68	77	58	77.2	71.2	1
Turkey	60	35	67	41	29	68	50	59	35.1	49.3	32
United Kingdom	67	63	75	55	67	70	63	74	67.8	66.8	9
United States	60	59	71	69	74	69	56	88	74.5	68.9	7

Legend	More than 85	80-85	75-80	70-75	65-70	60-65	55-60	50-55	40-50	40-45	Less than 40
	Best Practice					Moderate					Low

Freight digitisation best practice index

The freight digitisation best practice index is presented in **Figure 14** and **Table 7**. For the freight sector, the indices reported for individual functional areas were also estimated based on information documented in international case studies, and from government and industry reports including publicly available information on the relative performance of OECD countries for each functional area under freight.

The development and estimation of these indices was also informed by publicly available indicators including:

- Trade facilitation index (link)
- Trade facilitation and paperless trade index (link)
- Services trade restrictiveness index (link)
- Logistics performance index (link)
- Global resilience index (link)
- Ease of doing digital business index (link)

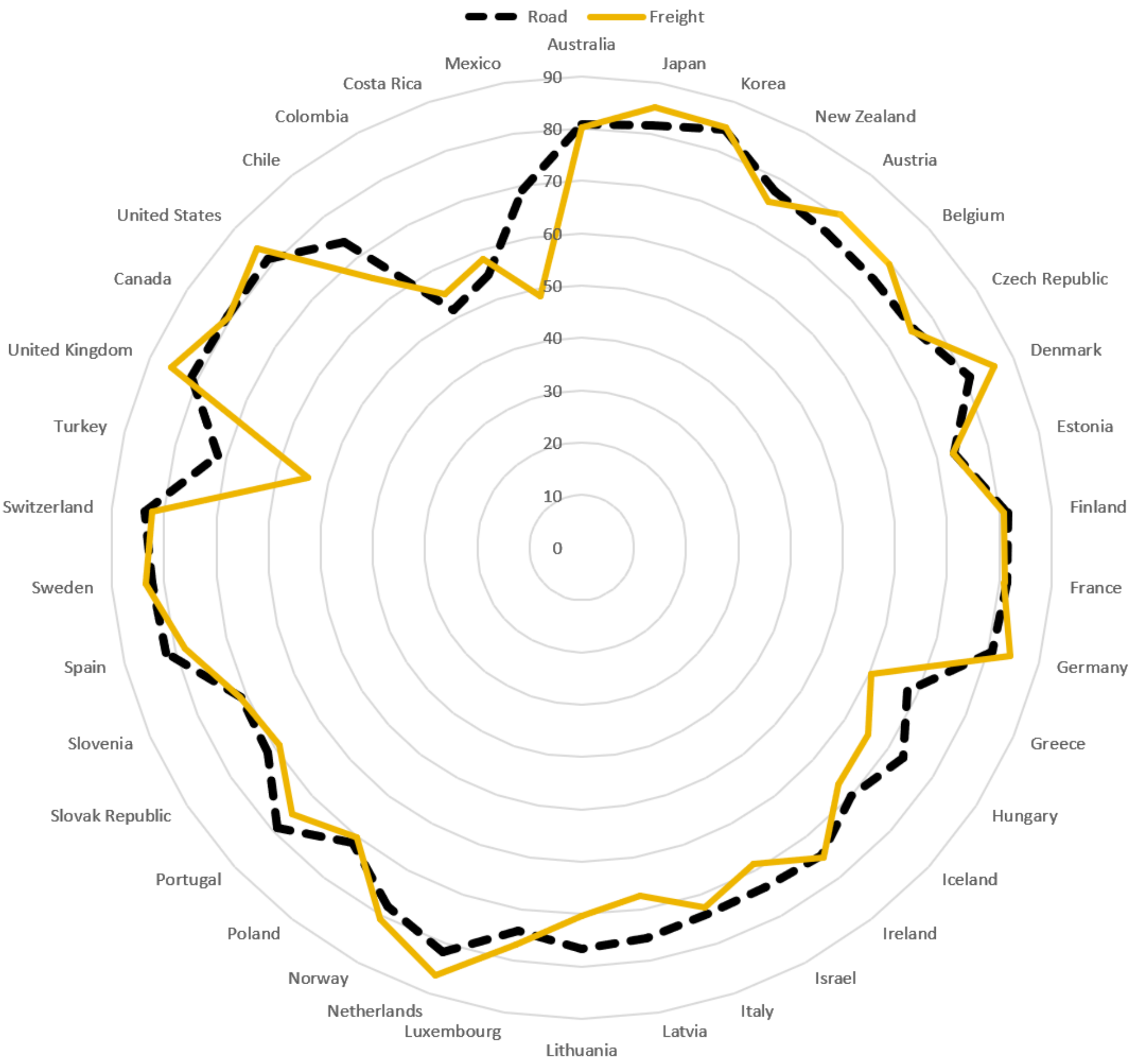


Figure 14: Freight digitisation best practice index – regional grouping

Table 7: Freight digitisation best practice index

OECD country	Warehousing and contract logistics	Last-mile delivery and urban freight	Trade facilitation and documentation	Freight forwarding and aggregation	Asset and cargo management	Technology-based services for e-commerce support	Country digitisation index score	Freight digitisation index score	Freight digitisation index ranking
BCR	1.0-1.2	1.0-4.8	10.8-17.5	1.1-2.9	1.0-3.1	TBC			
Australia	82	80	93	81	77	84	64.3	80.2	15
Austria	75	92	90	78	87	83	58.7	80.5	13
Belgium	77	93	90	77	84	81	56.7	79.9	16
Canada	83	79	88	85	79	81	69.0	80.5	14
Chile	81	61	82	78	67	39	47.6	65.1	33
Colombia	77	44	82	74	57	18	34.4	55.1	36
Costa Rica	70	37	82	72	56	52	38.7	58.3	35
Czech Republic	88	77	83	88	81	60	49.6	75.3	19
Denmark	85	91	87	86	90	89	75.0	86.2	2
Estonia	87	61	90	84	69	71	50.7	73.2	23
Finland	74	90	87	78	85	87	65.8	80.9	11
France	84	84	83	88	87	75	66.3	81.0	10
Germany	83	95	89	84	91	84	65.4	84.4	6
Greece	74	56	73	73	67	41	38.9	60.4	34
Hungary	77	65	72	80	76	40	47.9	65.2	32
Iceland	65	65	78	65	65	70	59.2	66.7	31
Ireland	80	69	88	81	74	77	56.3	75.1	21
Israel	77	60	76	74	73	64	57.2	68.8	29
Italy	73	80	82	77	79	68	49.1	72.6	24
Japan	83	92	92	82	88	95	64.7	85.3	4
Korea	90	80	94	83	85	88	74.6	84.8	5
Latvia	86	38	84	86	64	70	45.3	67.5	30
Lithuania	88	47	84	85	70	68	49.8	70.3	26
Luxembourg	81	75	74	85	80	82	62.2	76.9	18
Mexico	70	49	84	35	44	21	36.8	48.6	38
Netherlands	85	92	94	87	79	95	71.2	86.3	1
New Zealand	76	86	93	79	44	83	65.8	75.0	22
Norway	79	78	88	78	78	91	73.8	80.7	12
Poland	79	71	80	81	74	58	48.0	70.0	27
Portugal	86	75	81	85	81	68	50.8	75.3	20
Slovak Republic	83	48	82	84	68	72	45.9	68.9	28
Slovenia	77	61	87	82	69	74	51.1	71.3	25
Spain	80	84	87	80	84	75	57.3	78.3	17
Sweden	82	93	84	82	81	89	72.8	83.5	8
Switzerland	75	87	89	75	88	87	77.2	82.4	9
Turkey	66	53	82	69	61	11	35.1	53.9	37
United Kingdom	84	91	87	86	88	95	67.8	85.5	3
United States	79	86	91	78	85	95	74.5	84.3	7

Legend										
More than 85	80-85	75-80	70-75	65-70	60-65	55-60	50-55	40-50	40-45	Less than 40
Best Practice					Moderate					Low

Rail digitisation best practice index

The rail digitisation best practice index is presented in **Figure 15** and **Table 8**. For the rail sector, the indices reported for individual functional areas were also estimated based on information documented in international case studies, and from government and industry reports including publicly available information on the relative performance of OECD countries for each functional area under rail.

The development and estimation of these indices was also informed by publicly available indicators including:

- The global competitiveness report – using efficiency of train services score (link)
- Railway performance index (link)
- Resilience index data (link)
- ICT development index (link)

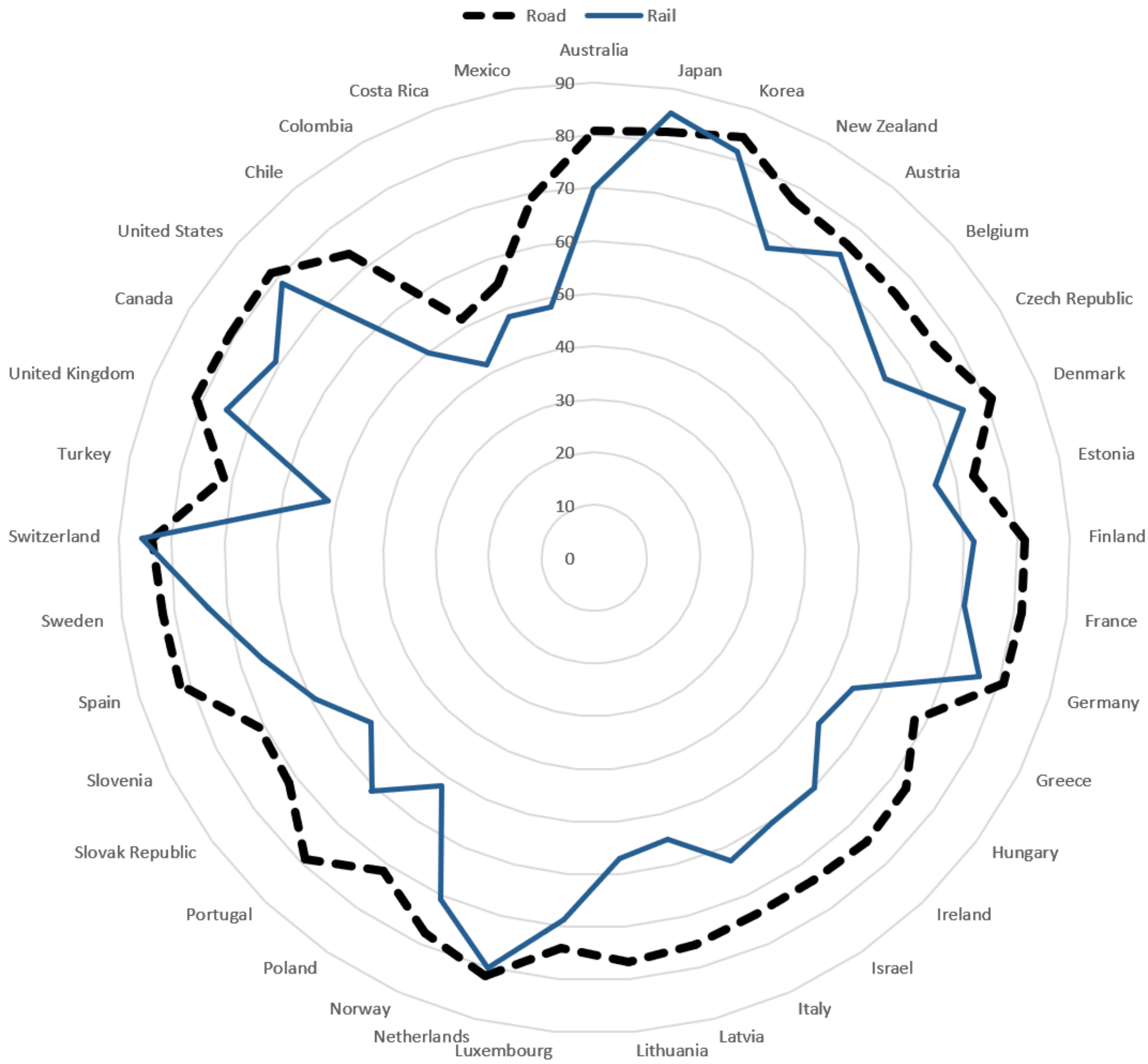


Figure 15: Rail digitisation best practice index – regional grouping

Table 8: Rail digitisation best practice index

OECD country	Information and communication technology services	Asset condition monitoring	Operations and track signalling	Country digitisation index score	Rail digitisation index score	Rail digitisation index ranking
BCR	1.0-2.6	1.5-1.6	1.4-2.6			
Australia	82	76	57	64.3	70.0	15
Austria	80	91	66	58.7	73.9	9
Belgium	78	88	49	56.7	67.9	17
Canada	78	79	58	69.0	70.8	12
Chile	66	72	36	47.6	49.8	34
Colombia	54	55	25	34.4	41.9	37
Costa Rica	64	61	30	38.7	48.5	35
Czech Republic	72	83	54	49.6	64.6	21
Denmark	87	88	64	75.0	75.2	7
Estonia	81	71	61	50.7	66.1	19
Finland	79	82	71	65.8	71.8	11
France	82	92	63	66.3	70.6	14
Germany	84	92	63	65.4	76.2	6
Greece	72	74	34	38.9	54.7	29
Hungary	69	79	41	47.9	52.8	30
Iceland	0	0	0	59.2	14.8	38
Ireland	80	73	44	56.3	60.2	25
Israel	79	82	45	57.2	60.2	24
Italy	70	83	49	49.1	62.9	22
Japan	84	97	96	64.7	85.4	2
Korea	89	95	81	74.6	81.4	3
Latvia	73	72	47	45.3	55.0	28
Lithuania	72	73	49	49.8	57.0	27
Luxembourg	85	85	59	62.2	68.7	16
Mexico	52	67	38	36.8	48.2	36
Netherlands	85	98	66	71.2	80.1	4
New Zealand	83	71	49	65.8	67.3	18
Norway	85	71	53	73.8	70.8	13
Poland	69	79	39	48.0	52.0	32
Portugal	71	83	39	50.8	61.0	23
Slovak Republic	71	75	41	45.9	52.5	31
Slovenia	74	75	37	51.1	59.2	26
Spain	78	93	61	57.3	65.6	20
Sweden	84	83	55	72.8	73.7	10
Switzerland	87	97	81	77.2	85.7	1
Turkey	61	69	41	35.1	51.6	33
United Kingdom	87	90	55	67.8	75.0	8
United States	82	89	69	74.5	78.6	5

Legend										
More than 85	80-85	75-80	70-75	65-70	60-65	55-60	50-55	40-50	40-45	Less than 40
Best Practice					Moderate					Low

Aviation and air transport digitisation best practice index

The aviation and air transport digitisation best practice index is presented in **Figure 16** and **Table 9**. The indices reported for individual functional areas were also estimated based on information documented in international case studies, and from government and industry reports including publicly available information on the relative performance of OECD countries for each functional area under aviation.

The development and estimation of these indices was also informed by publicly available indicators including:

- The GCI – using efficiency of air transport services and airport connectivity indices (link)
- The travel and tourism competitiveness index (link)
- Government surveillance and security index (link)

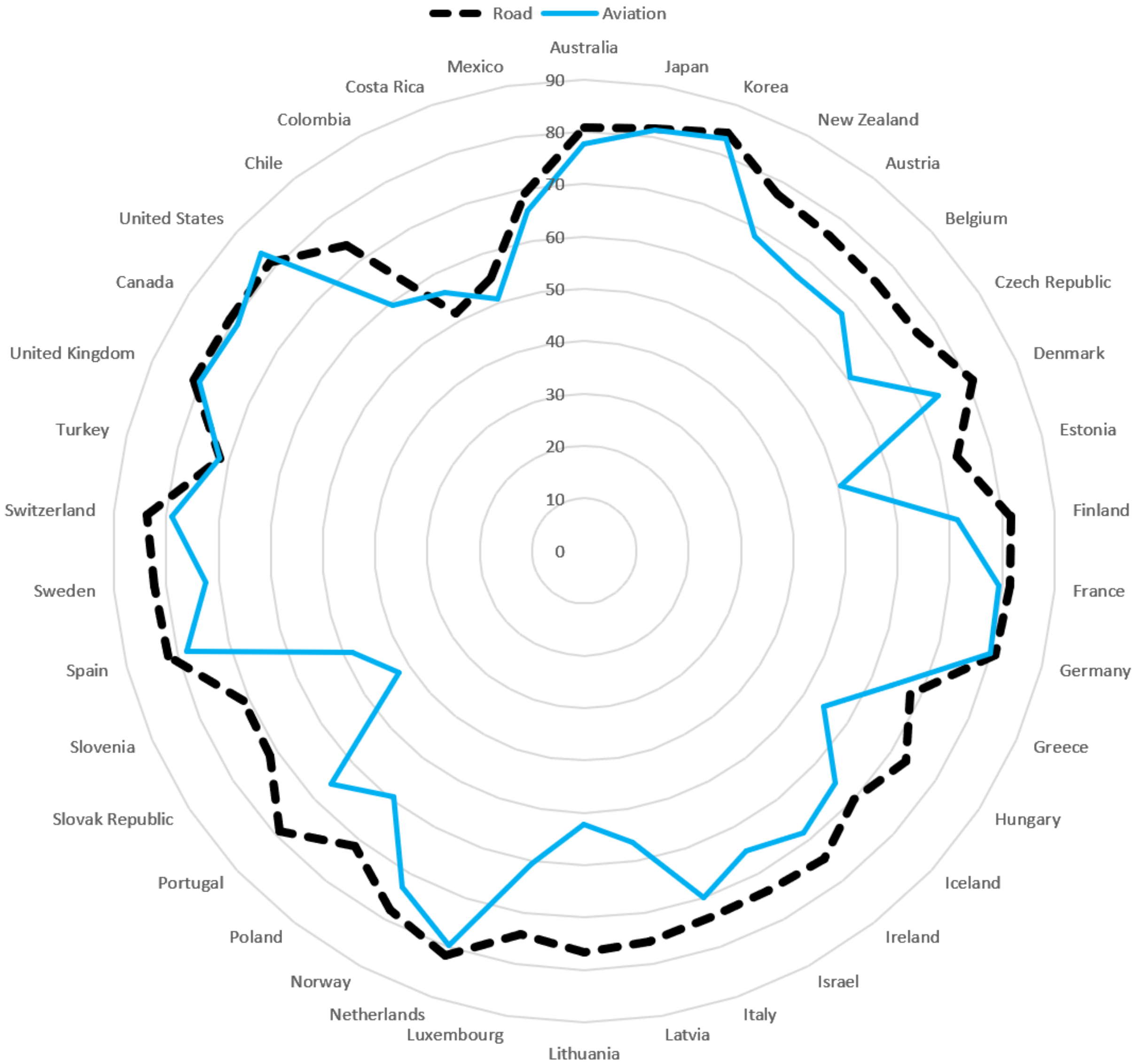


Figure 16: Aviation digitisation best practice index – regional grouping

Table 9: Aviation and air transport digitisation best practice index

OECD country	Airport safety and security	Airport operations	Capacity management	Country digitisation index score	Aviation digitisation index score	Aviation digitisation index ranking
BCR	1.0-30.0	1.0-4.0	10.8-17.5			
Australia	77	83	86	64.3	77.7	11
Austria	68	71	68	58.7	66.2	21
Belgium	67	73	69	56.7	66.7	20
Canada	79	84	84	69.0	79.0	8
Chile	64	65	62	47.6	59.4	29
Colombia	64	62	63	34.4	56.0	32
Costa Rica	55	57	53	38.7	50.9	35
Czech Republic	64	67	62	49.6	60.6	27
Denmark	71	76	73	75.0	73.7	12
Estonia	52	52	47	50.7	50.4	36
Finland	68	79	74	65.8	71.6	16
France	81	85	85	66.3	79.3	7
Germany	81	86	87	65.4	80.0	5
Greece	69	73	75	38.9	64.0	26
Hungary	56	58	56	47.9	54.5	33
Iceland	66	72	64	59.2	65.3	24
Ireland	71	74	71	56.3	68.3	19
Israel	66	70	67	57.2	65.1	25
Italy	73	76	81	49.1	70.0	17
Japan	79	89	93	64.7	81.5	3
Korea	86	85	87	74.6	83.3	2
Latvia	58	64	59	45.3	56.3	31
Lithuania	54	55	51	49.8	52.2	34
Luxembourg	58	65	57	62.2	60.6	28
Mexico	79	72	75	36.8	65.7	23
Netherlands	77	87	83	71.2	79.6	6
New Zealand	67	72	68	65.8	68.4	18
Norway	71	76	72	73.8	72.9	13
Poland	62	63	64	48.0	59.4	30
Portugal	71	72	70	50.8	65.8	22
Slovak Republic	46	41	37	45.9	42.3	38
Slovenia	48	50	45	51.1	48.4	37
Spain	81	87	88	57.3	78.4	10
Sweden	69	76	73	72.8	72.4	14
Switzerland	75	83	81	77.2	79.0	9
Turkey	86	82	84	35.1	71.9	15
United Kingdom	82	85	86	67.8	80.2	4
United States	82	89	90	74.5	83.8	1

Legend										
More than 85	80-85	75-80	70-75	65-70	60-65	55-60	50-55	40-50	40-45	Less than 40
Best Practice					Moderate					Low

Maritime and shipping digitisation best practice index

The maritime and shipping digitisation best practice index is presented in **Figure 17** and **Table 10**. The indices reported for individual functional areas were also estimated based on information documented in international case studies, and from government and industry reports, including publicly available information on the relative performance of OECD countries for each functional area under maritime and shipping.

The development and estimation of these indices was also informed by publicly available indicators including:

- Quality of port infrastructure index (link)
- The GCI using efficiency of seaport services and liner shipping connectivity sub-indices (link)
- FM Global resilience index (link)
- Services trade restrictiveness index (link)
- The leading maritime capitals of the world (Menon Economics) available on this link

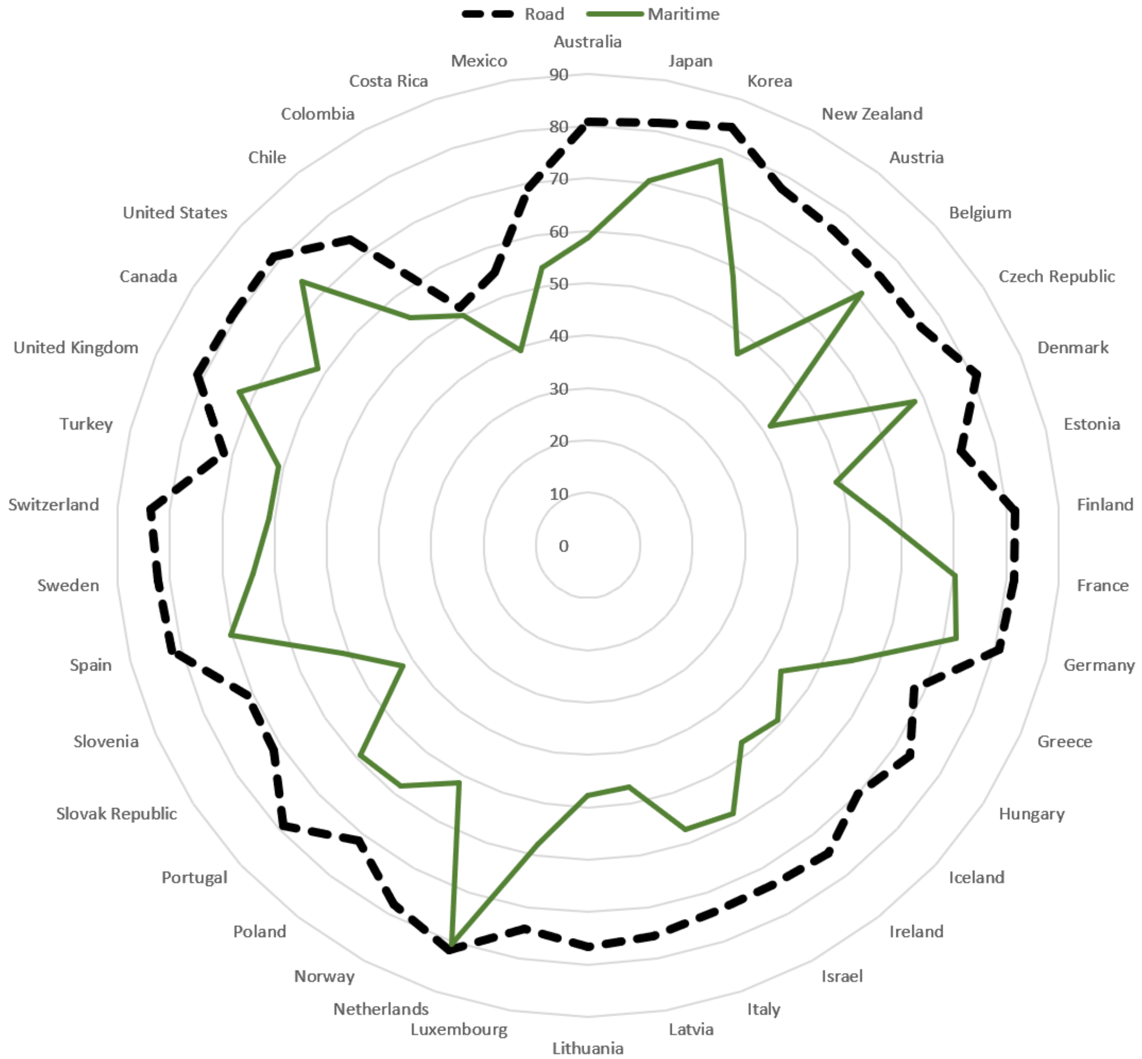


Figure 17: Maritime digitisation best practice index – regional grouping

Table 10: Maritime and shipping digitisation best practice index

OECD country	Safety and security	Port operations	Administrative procedures	Ocean and short-sea shipping	Maritime traffic management	Country digitisation index Score	Maritime digitisation index score	maritime digitisation index ranking
BCR	1.4-8.1	1.9-3.1	10.8-17.5	1.0-1.7	5.1-10.2			
Australia	50	69	63	55	50	64.3	58.5	16
Austria	37	53	44	52	32	58.7	46.2	34
Belgium	39	80	76	83	91	56.7	70.9	6
Canada	40	73	68	67	52	69.0	61.5	12
Chile	43	70	66	61	43	47.6	55.1	23
Colombia	42	59	52	63	50	34.4	49.9	28
Costa Rica	33	56	49	44	16	38.7	39.3	38
Czech Republic	33	46	37	50	34	49.6	41.5	37
Denmark	44	83	79	69	59	75.0	68.1	10
Estonia	38	80	76	40	7	50.7	48.8	30
Finland	39	91	90	43	13	65.8	56.9	22
France	44	74	69	83	84	66.3	70.2	9
Germany	38	74	71	90	97	65.4	72.4	5
Greece	39	69	63	60	59	38.9	54.7	24
Hungary	52	46	36	42	40	47.9	43.9	35
Iceland	45	77	74	35	5	59.2	49.2	29
Ireland	35	71	67	46	11	56.3	47.6	32
Israel	56	69	63	58	47	57.2	58.2	18
Italy	29	67	61	70	67	49.1	57.2	21
Japan	40	83	80	79	77	64.7	70.5	7
Korea	52	79	74	85	100	74.6	77.5	2
Latvia	46	70	65	46	8	45.3	46.8	33
Lithuania	33	69	63	51	21	49.8	47.7	31
Luxembourg	43	63	57	60	62	62.2	57.9	20
Mexico	59	61	55	61	49	36.8	53.7	25
Netherlands	39	91	91	92	98	71.2	80.4	1
New Zealand	50	70	66	48	50	65.8	58.2	19
Norway	44	73	69	42	8	73.8	51.6	26
Poland	45	64	59	70	63	48.0	58.2	17
Portugal	29	70	65	74	65	50.8	59.0	15
Slovak Republic	44	44	36	42	42	45.9	42.3	36
Slovenia	34	67	62	54	39	51.1	51.2	27
Spain	39	77	73	85	90	57.3	70.2	8
Sweden	42	76	71	64	60	72.8	64.2	11
Switzerland	41	64	59	62	64	77.2	61.1	13
Turkey	77	67	62	66	60	35.1	61.0	14
United Kingdom	40	74	69	88	96	67.8	72.6	4
United States	38	80	76	81	97	74.5	74.3	3

Legend	More than 85	80-85	75-80	70-75	65-70	60-65	55-60	50-55	40-50	40-45	Less than 40
	Best Practice					Moderate					Low

Common functional areas across multiple sectors

The common functional areas digitisation best practice indices are presented in **Figure 18** and **Table 11**. These indices were also estimated based on information documented in international case studies, and from government and industry reports, including publicly available information on the relative performance of OECD countries for each functional area under maritime and shipping.

The development and estimation of these indices was also informed by publicly available indicators including:

- FM Global resilience index (link)
- The GCI using transport infrastructure, liner shipping connectivity scores, quality of air transport infrastructure and airport connectivity (link)
- Quality of port infrastructure index **(**link)
- Logistics performance index (link)

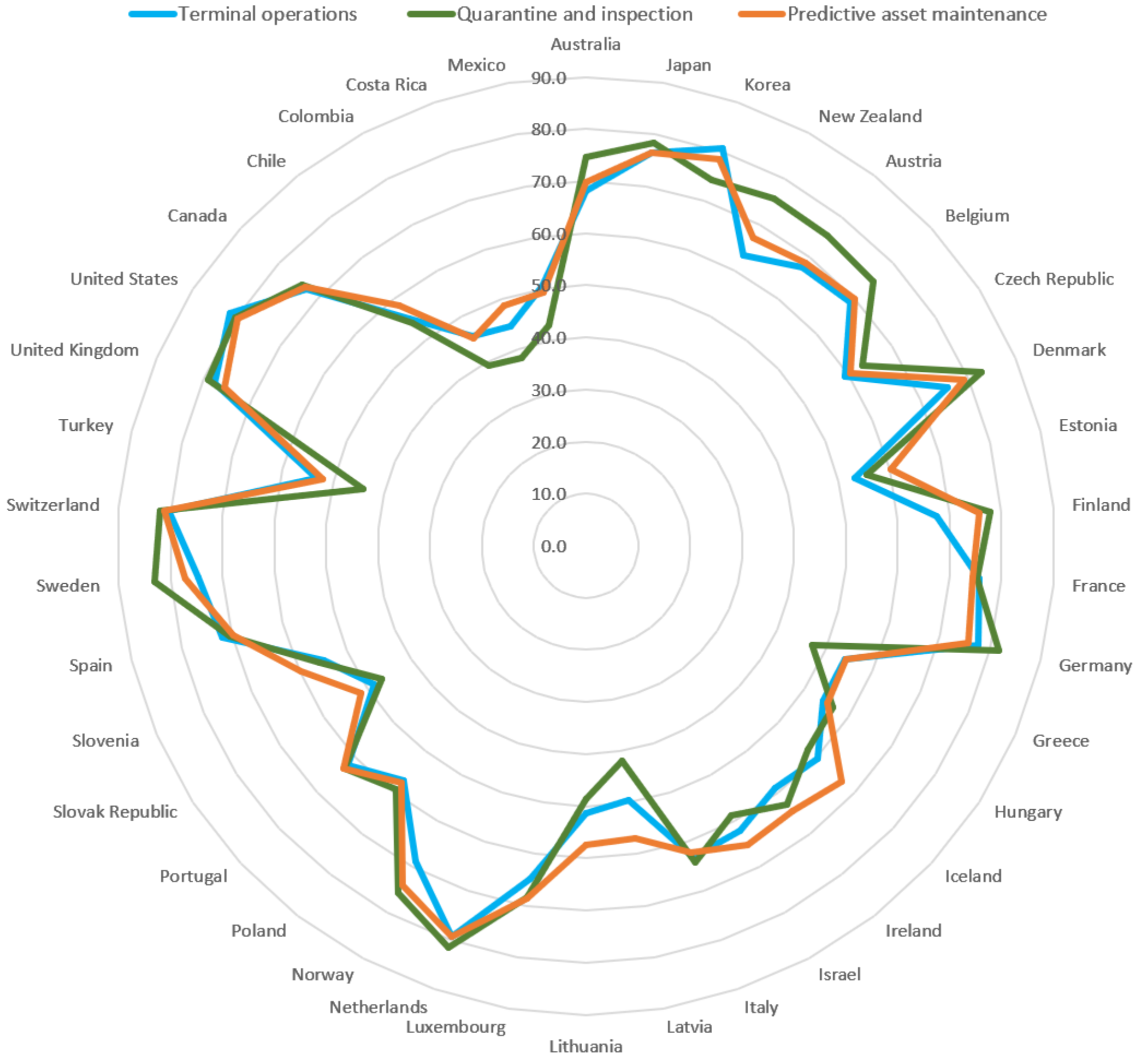


Figure 18: Common functional areas best practice indices – regional grouping

Table 11: Common functional areas digitisation best practice indices

OECD country	Terminal operations and management	Country digitisation index score	Terminal operations digitisation index score	Terminal operations digitisation index ranking	Quarantine and inspection	Country digitisation index score	Quarantine digitisation index score	Quarantine digitisation index ranking	Infrastructure services and predictive maintenance	Country digitisation index score	Infrastructure services digitisation index score	Infrastructure services digitisation index ranking
BCR	2.6-3.7				7.9-15.3				1.0-3.3			
Australia	72	64.3	68.2	15	85	64.3	74.7	15	75	64.3	69.8	16
Austria	77	58.7	67.6	16	92	58.7	75.5	12	79	58.7	68.7	17
Belgium	81	56.7	69.1	13	93	56.7	74.8	14	83	56.7	70.0	14
Canada	77	69.0	72.8	11	79	69.0	74.0	17	78	69.0	73.3	13
Chile	63	47.6	55.2	27	61	47.6	54.2	30	69	47.6	58.3	28
Colombia	57	34.4	45.8	37	44	34.4	39.2	37	56	34.4	45.3	38
Costa Rica	50	38.7	44.5	38	37	38.7	38.1	38	59	38.7	48.7	37
Czech Republic	69	49.6	59.3	24	77	49.6	63.3	21	71	49.6	60.5	25
Denmark	76	75.0	75.6	8	91	75.0	82.9	2	83	75.0	79.1	4
Estonia	56	50.7	53.1	32	61	50.7	55.6	29	70	50.7	60.2	26
Finland	69	65.8	67.5	17	90	65.8	77.8	9	86	65.8	75.8	9
France	85	66.3	75.6	9	84	66.3	75.2	13	83	66.3	74.4	11
Germany	90	65.4	77.5	6	98	65.4	81.7	4	86	65.4	75.8	9
Greece	70	38.9	54.2	30	56	38.9	47.3	32	70	38.9	54.5	33
Hungary	61	47.9	54.3	29	65	47.9	56.6	27	63	47.9	55.3	32
Iceland	61	59.2	60.3	23	57	59.2	57.9	26	74	59.2	66.7	20
Ireland	62	56.3	58.9	25	69	56.3	62.8	23	73	56.3	64.4	22
Israel	67	57.2	62.1	22	60	57.2	58.8	25	74	57.2	65.4	21
Italy	77	49.1	63.2	20	80	49.1	64.3	20	75	49.1	62.2	24
Japan	88	64.7	76.5	7	92	64.7	78.5	8	88	64.7	76.5	7
Korea	87	74.6	80.7	2	74	74.6	74.2	16	82	74.6	78.5	5
Latvia	54	45.3	49.5	35	38	45.3	41.8	36	69	45.3	56.9	31
Lithuania	53	49.8	51.3	33	47	49.8	48.6	31	65	49.8	57.3	30
Luxembourg	67	62.2	64.8	18	75	62.2	68.4	19	75	62.2	68.5	18
Mexico	64	36.8	50.5	34	49	36.8	42.9	35	62	36.8	49.2	36
Netherlands	88	71.2	79.4	4	92	71.2	81.6	5	88	71.2	79.4	3
New Zealand	61	65.8	63.3	19	86	65.8	75.7	11	69	65.8	67.3	19
Norway	64	73.8	68.9	14	78	73.8	75.7	10	74	73.8	74.1	12
Poland	66	48.0	57.0	26	71	48.0	59.3	24	67	48.0	57.6	29
Portugal	74	50.8	62.2	21	75	50.8	63.0	22	75	50.8	63.1	23
Slovak Republic	51	45.9	48.6	36	48	45.9	46.9	33	57	45.9	51.5	35
Slovenia	59	51.1	55.0	28	61	51.1	55.9	28	69	51.1	59.8	27
Spain	87	57.3	71.9	12	84	57.3	70.5	18	82	57.3	69.8	15
Sweden	76	72.8	74.6	10	93	72.8	83.1	1	82	72.8	77.2	6
Switzerland	84	77.2	80.4	3	87	77.2	82.0	3	85	77.2	81.1	1
Turkey	72	35.1	53.4	31	53	35.1	44.1	34	69	35.1	52.2	34
United Kingdom	88	67.8	77.8	5	91	67.8	79.2	7	84	67.8	75.8	8
United States	89	74.5	81.7	1	86	74.5	80.3	6	85	74.5	79.9	2

Legend

More than 85 | 80-85 | 75-80 | 70-75 | 65-70 | 60-65 | 55-60 | 50-55 | 40-50 | 40-45 | Less than 40

Best Practice | Moderate | Low

Active transport digitisation best practice index

The active transport digitisation best practice index is presented in **Figure 19** and **Table 12.** The index was estimated based on information documented in international case studies and government and industry reports, including publicly available information on the relative performance of OECD countries for each functional area under active transport.

The development and estimation of these indices was also informed by publicly available indicators including:

- Smart city index (link)
- Bicycle cities index (link)

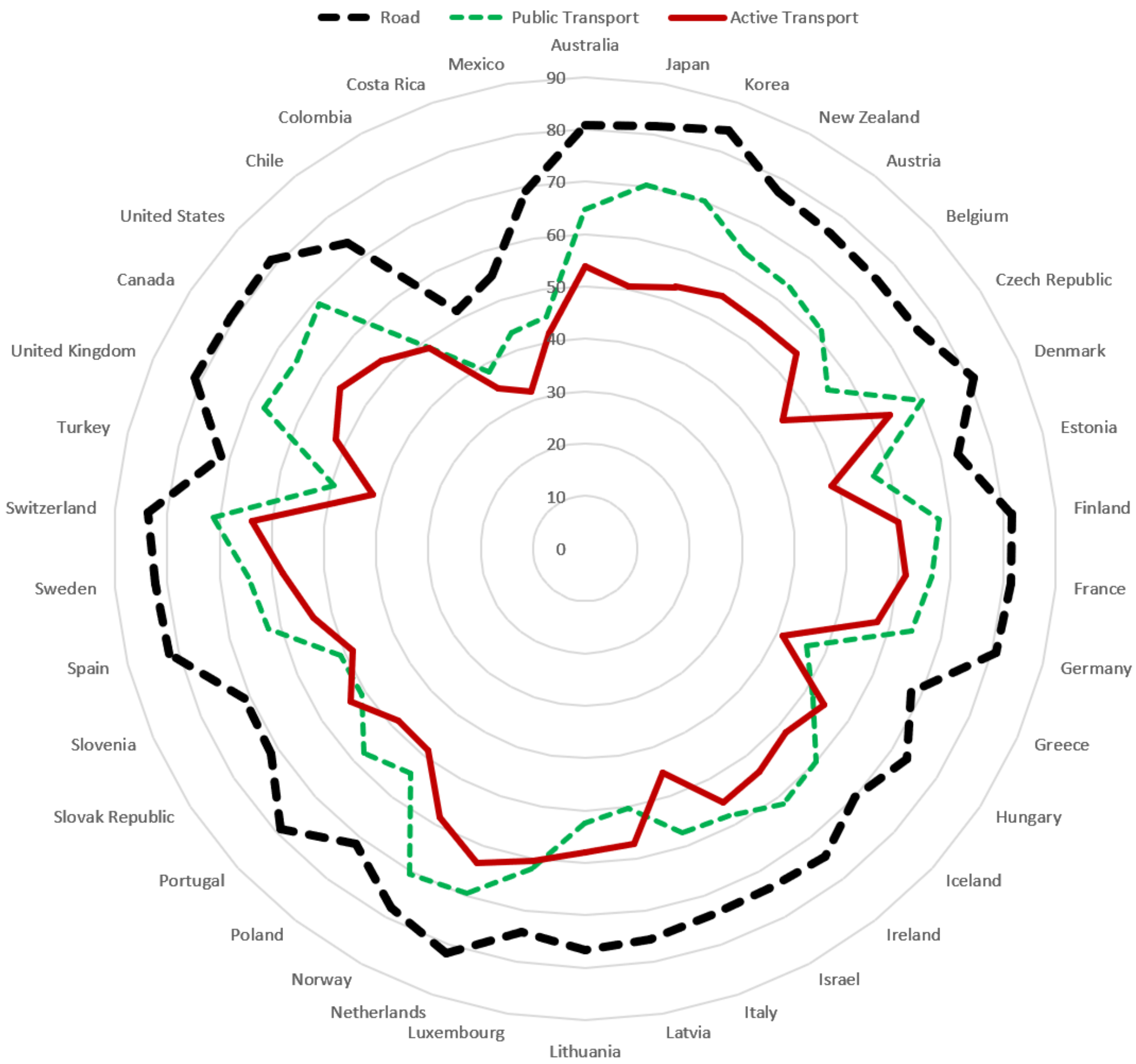


Figure 19: Active transport digitisation best practice indices – regional grouping

Table 12: Active transport digitisation best practice index

OECD country	Safety of riders and vulnerable road users	Parking management	Fleet management	Traveller experience	Country digitisation index score	Active transport digitisation index score	Active transport digitisation index ranking
BCR	1.3-4.9	2.5-4.7	2.0-3.5	1.0-4.0			
Australia	96	42	39	29	64.3	53.9	19
Austria	81	52	40	41	58.7	54.4	16
Belgium	78	44	46	50	56.7	54.9	14
Canada	84	48	40	39	69.0	56.0	12
Chile	83	49	30	34	47.6	48.6	28
Colombia	54	38	22	26	34.4	34.7	37
Costa Rica	30	30	30	30	38.7	31.7	38
Czech Republic	84	38	26	27	49.6	44.9	33
Denmark	83	57	60	43	75.0	63.6	2
Estonia	60	36	60	36	50.7	48.5	29
Finland	90	57	37	51	65.8	60.1	6
France	87	57	41	55	66.3	61.3	4
Germany	90	49	43	40	65.4	57.4	10
Greece	86	31	29	21	38.9	41.2	36
Hungary	60	52	60	52	47.9	54.4	17
Iceland	90	48	33	30	59.2	51.9	24
Ireland	87	50	30	47	56.3	54.0	18
Israel	82	49	37	51	57.2	55.1	13
Italy	78	40	28	32	49.1	45.3	32
Japan	81	40	40	28	64.7	50.7	26
Korea	86	45	28	30	74.6	52.8	23
Latvia	60	60	60	60	45.3	57.1	11
Lithuania	60	60	60	60	49.8	58.0	8
Luxembourg	60	60	60	60	62.2	60.4	5
Mexico	76	42	24	30	36.8	41.6	35
Netherlands	80	53	69	44	71.2	63.4	3
New Zealand	90	49	35	34	65.8	54.7	15
Norway	91	49	31	47	73.8	58.3	7
Poland	86	44	29	37	48.0	48.8	27
Portugal	73	52	30	37	50.8	48.5	31
Slovak Republic	60	51	60	51	45.9	53.6	20
Slovenia	84	36	35	37	51.1	48.5	30
Spain	79	53	35	44	57.3	53.6	21
Sweden	92	47	43	35	72.8	57.9	9
Switzerland	84	60	43	55	77.2	63.8	1
Turkey	77	43	25	29	35.1	41.7	34
United Kingdom	82	43	35	32	67.8	51.9	25
United States	71	49	31	39	74.5	52.8	22

Legend	More than 85	80-85	75-80	70-75	65-70	60-65	55-60	50-55	40-50	40-45	Less than 40
	Best Practice					Moderate					Low

Overall transport and freight digitisation best practice index

An overall index based on each country's digitisation best practice in road, public transport, freight, rail, aviation and maritime sectors is also provided in **Figure 20 and Table 13** . The active transport digitisation best practice index was excluded from this analysis mainly because it has been considered an emerging sector in terms of digitisation, particularly outside the US and Europe. Although an overall index for Iceland is included in **Table 13**, the index does not include the rail component because the country does not have a public railway system. The score for Iceland was instead based on equal weightings for the remaining sectors.

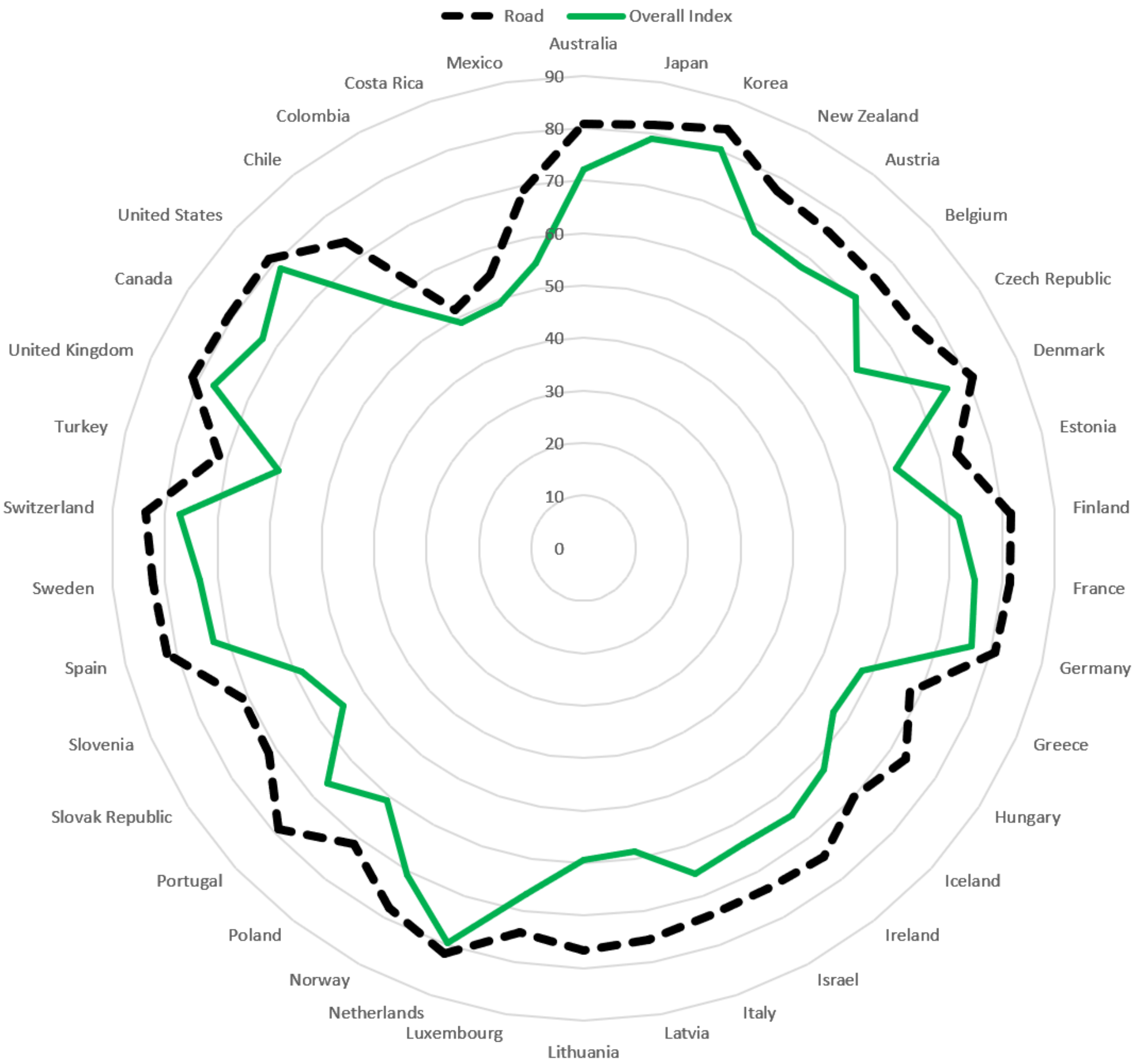


Figure 20: Overall transport and freight digitisation index – regional grouping

Table 13: Overall transport and freight digitisation index – regional grouping

OECD Country	Road	Public Transport	Freight	Aviation	Maritime	Rail	Overall Index	Overall Rank
Australia	81	65	80	78	59	70	72	13
Japan	82	70	85	81	70	85	79	3
Korea	84	70	85	83	78	81	80	1
New Zealand	77	64	75	68	58	67	68	17
Austria	76	63	80	66	46	74	68	18
Belgium	76	61	80	67	71	68	70	16
Czech Republic	76	55	75	61	41	65	62	24
Denmark	81	70	86	74	68	75	76	8
Estonia	73	57	73	50	49	66	61	26
Finland	81	68	81	72	57	72	72	14
France	81	66	81	79	70	71	75	9
Germany	81	64	84	80	72	76	76	7
Greece	68	46	60	64	55	55	58	33
Hungary	73	52	65	54	44	53	57	34
Iceland	70	60	67	65	49	--	62	25
Ireland	75	62	75	68	48	60	65	22
Israel	74	58	69	65	58	60	64	23
Italy	74	57	73	70	57	63	66	21
Latvia	76	50	68	56	47	55	59	32
Lithuania	77	52	70	52	48	57	59	29
Luxembourg	74	62	77	61	58	69	67	19
Netherlands	82	70	86	80	80	80	80	2
Norway	78	71	81	73	52	71	71	15
Poland	71	54	70	59	58	52	61	27
Portugal	79	58	75	66	59	61	66	20
Slovak Republic	72	51	69	42	42	53	55	36
Slovenia	71	51	71	48	51	59	59	30
Spain	82	62	78	78	70	66	73	12
Sweden	82	64	83	72	64	74	73	10
Switzerland	84	71	82	79	61	86	77	5
Turkey	72	49	54	72	61	52	60	28
United Kingdom	81	67	86	80	73	75	77	6
Canada	81	66	80	79	62	71	73	11
United States	81	69	84	84	74	79	79	4
Chile	74	49	65	59	55	50	59	31
Colombia	52	38	55	56	50	42	49	38
Costa Rica	55	44	58	51	39	49	49	37
Mexico	69	45	49	66	54	48	55	35

Stakeholder consultations

Stakeholder consultations

For the stakeholder consultation, a survey was developed and distributed among senior executives from the transport and freight sectors. More than 200 participants were invited to participate representing government, industry, research organisations and peak bodies. Participants were provided with a summary report that documented key issues considered in this research and were asked to share their insights and provide feedback.

At a glance

The data collection was completed on 11 October 2021. A total of 27 responses were received, with participants representing various parts of the industry, including, active transport, rail, road, and maritime. The majority of participants presented themselves as cross-sectoral organisations. From the 27 participants, 22 had some involvement in the freight sector, representing around 80% of the total sample. Furthermore, all the questions were answered by the 27 participants, except the final question which was an open-ended question to provide an opportunity to participants to freely express their views out of the survey structure. The information presented here is the combination of respondents' original input and researchers' interpretation through a qualitative thematic analysis. Please note, given the small size of the sample, the analysis provided in this section is more descriptive and reflective, rather than statistically verified.

Question 1: Top three challenges

The first question of the survey was aimed to capture the top three challenges facing the Australian transport and freight industry in adoption of digitisation. Given the diverse nature of participants' operations, the responses to this question varied from lack of motivation and incentives in the industry to adopt technology, to issues related to trusted data and cybersecurity. **Figure 21** illustrates the key areas.

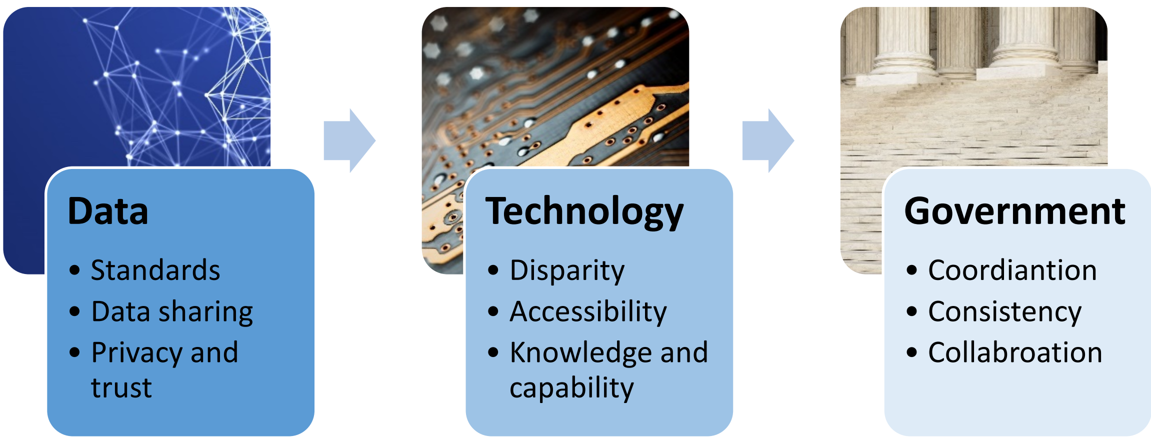


Figure 21: Top three challenges facing digitisation in transport and freight

- Data as an enabler of digitisation: The majority of respondents have highlighted the essential role of data as an enabler towards digitisation in the transport and freight sector. Within the challenges related to data, three themes are evident. First, lack of standards and nationally accepted mechanisms for collection and sharing of transport and freight data. Second, perceived commercialisation of data by the private sector. And third, trust, privacy and cybersecurity concerns.

- Technology maturity: The survey respondents identified and highlighted a series of challenges related to technology maturity. The first theme relates to technology disparity among the industry and jurisdictions. One respondent also highlighted that large players with vertically integrated operations have legacy systems, which could be expensive and infeasible to change. Respondents expressed concerns about the use of various technological options and standards by different agencies and industries, especially when considering the interface with the infrastructure. The second theme relates to technology accessibility and capability building, particularly lack of a sufficiently dynamic digital technology industry and skills. Third, respondents also highlighted the importance of having the required knowledge and understanding about the role and wider benefits of technology towards a more competitive transport and freight industry. One respondent underlined that small and medium sized enterprises (SMEs) are not technology savvy and lack technology resources, which is important when considering the market freight fragmentation that involves a large number of small players.
- **Government coordination and regulation:** The key topic shared in this challenge area relates to the role of government and regulatory aspects of digitisation. First, respondents highlighted the need for further coordination among different levels of government for facilitating digitisation of transport and freight. Different approaches to adoption of digital technologies was also identified as a challenge, whether across different levels of government and boundaries, functional areas and/or operators. Therefore, the need for strong leadership from governments to establish and support a vision to influence and promote the adoption of digitisation in transport and freight, was highlighted as an initial step. Second, lack of cohesion and consistency among jurisdiction and regulatory bodies was identified as a challenge. One respondent identified the existing gap of regulations for CAVs for ICT needs and also decisions related to pricing regimes of the future transport network. Finally, further coordination and synchronisation between government and industry, to better understand the role of each party and to identify the needs of industry was observed as an important area.

Further challenges were also identified, including implementation costs, lack of motivation by the private sector to adopt technology in an agile fashion and fragmentation in the industry as the result of asymmetric business models.

Question 2: The opportunities

The second question of the survey was aimed to capture the view of industry on the main opportunities for the adoption of digitisation in the Australian transport and freight industry. The captured information has identified various opportunities ranging from improved infrastructure decision making to societal and environmental benefits. The key opportunity areas are summarised as below.

- **Supply chain and operational efficiency:** A large portion of the respondents have emphasised the productivity benefits that digitisation could bring at supply chain and operational levels. Digital technologies could facilitate the access to real-time and reliable data, which is essential to improve operational efficiency, asset utilisation and automation. Such improvements could also contribute to enhanced supply chain visibility, which is key for planning purposes, inventory optimisation and process improvement among various supply chain actors. Respondents also emphasised the cost reduction opportunities as the result of implementing digital technologies in the transport and freight sector. The input from participants also show that digitisation could streamline regulatory conformance, which again is a desirable attribute for transport and supply chain efficiency. One respondent also emphasised the potential benefits of digitisation towards standardisation, which could lead to process simplification cross the industry.
- **Optimised infrastructure investment and enhanced planning**: Survey participants recognised various opportunities that digitisation could bring for utilisation, planning and

investment in the infrastructure. First, digitisation could play an enabling role in better understanding of the trade and freight patterns, therefore assisting decision-makers for future infrastructure investment. Such data could provide important insight on the key infrastructure bottlenecks, but also identifying demand priority areas in the transport and freight network. The ability to collect and analyse data through digital technologies from infrastructure is key to enhanced investment, better accessibility and supply chain productivity. One respondent also highlighted that digital technologies could contribute to network resilience and responsiveness through smart infrastructure management.

- **Social and environmental benefits:** The important role of transport and freight digitisation towards achieving environmental and social objectives was also highlighted by survey participants. In particular, digital technologies (e.g. fleet electrification and optimisation) could significantly contribute to lower levels of GHG emissions. Also, respondents highlighted that digitisation could assist with risk identification and also enhanced safety for both operators and users through predictive tools. One participant also identified the role of digital technologies to achieve accessibility and equity outcomes.

Question 3: Key concerns as a consequence of digitisation

One of the objectives of the stakeholder consultation was to investigate what are the most important concerns or threats to the adoption of digital technologies in the transport and freight industries. Similar to Question 1, which investigated the top challenges, data-related concerns remain the most important area.

- **Data-related concerns:** For many respondents, digitisation could arrive with data-related concerns, which could potentially minimise the effectiveness of adoption. First, and most importantly, a large number of participants have highlighted the challenges related to cyber-physical resilience of digital systems. In particular, cybersecurity was considered as a top concern when digitally integrating complex and multi-layer transport networks. Second, data privacy was highlighted as a key issue, particularly if identifiable data is captured and shared as the result of adoption of digital technologies in vehicles and on the infrastructure. Some respondents also emphasised that privacy concerns could reduce the willingness of users and operators to share data with government and industry.

- **Adoption without vision:** Survey participants highlighted that, without appropriate vision and regulatory frameworks, the industry could end up with significant duplication of digital systems. To avoid such a mistake, it was suggested that a clear government role is required to clearly support, invest and facilitate the adoption of digital technologies in the transport and freight sector. Furthermore, it was highlighted that while national initiatives could prioritise a particular technology area, local readiness could be different in terms of speed and scope, particularly until the technology becomes mainstream. Finally, as part of vision development, appropriate standardisation and interoperability mechanisms must be introduced and agreed, to encourage and facilitate the trends in digitisation.

- **Appropriate risk–reward mechanisms:** It was also apparent that some participants have concerns about the wider implications of digitisation on the market structure and competitive landscape. One respondent stated that digitisation could result in the ‘potential long-term dominance of big tech players’. Another respondent also emphasised the potential risks of digitisation for smaller players, as a result of slow uptake of technology and loss of market share. Furthermore, it was highlighted that digitisation could create a burden of cost and compliance amongst industry, rather than a facilitating mechanism. Therefore, the gains achieved through digitisation should be shared equally among the industry.

- **Safety and social outcomes:** Respondents also highlighted important concerns regarding the social and safety outcomes of adopting digital technologies in the transport and freight sector. For example, one respondent emphasised that digitisation must be seen as an enabler to minimise the gap in social inequity. In particular, job security was highlighted as a concern, such as truck drivers losing benefits as a result of adopting digital technologies and further automation. Additionally, it was highlighted that if digitisation is implemented poorly, higher costs could be passed onto the community and users. On the other hand, concerns were also raised related to safety implications of digitisation. One respondent stated:

  > If digitisation is implemented poorly and creates intense competition in the trucking arena this will work against improved safety and sustainability outcomes.

  Furthermore, the results showed that the safety implications of adopting CAVs and other automated transport systems is an important area, especially when interacting with their wider environment (e.g. vulnerable road users).

Question 4: The organisational and industrial impacts of digitisation

In this question, participants were asked to reflect on how their organisations could be impacted as a result of digitisation in transport and freight. Such information is important to capture the views of industry on whether they see such digital trends as an opportunity or threat for their organisation and the wider industry. Furthermore, given the fact the industry participants presented various functional areas, such information could provide a more complete understanding of the future landscape of freight and transport in the face of digitisation. Respondents' perception of digitisation has been classified into positive, negative, mixed view, not applicable and unsure (**Figure 22**).

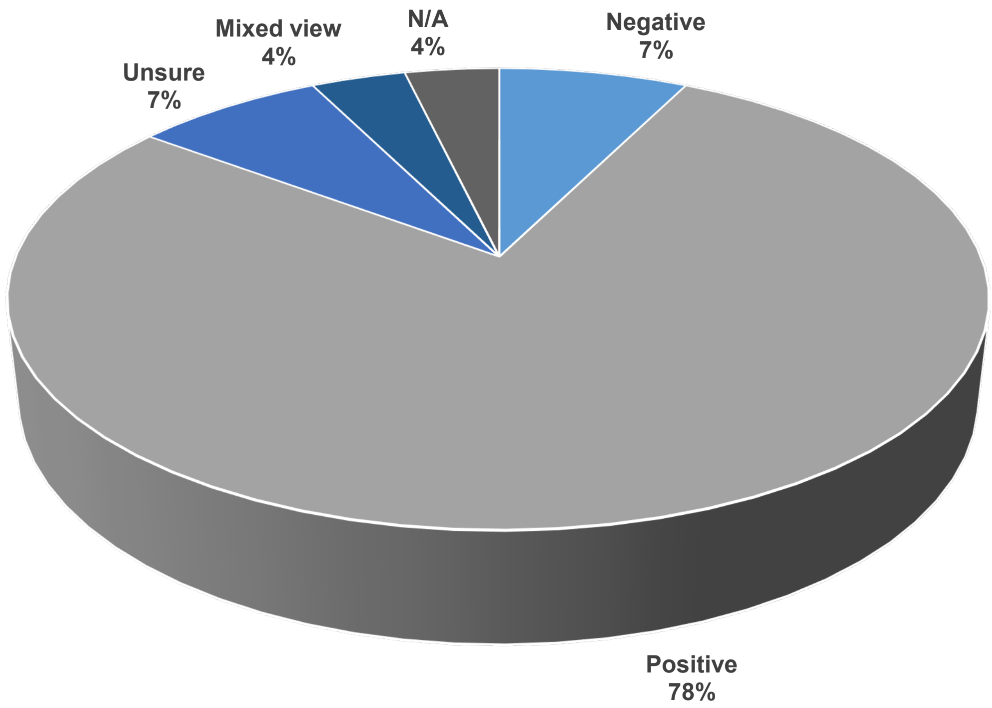


Figure 22: Participant sentiment on future impacts of digitisation on their organisations

- **Positive:** The majority of respondents (77%) demonstrated a positive sentiment towards the future impacts of digitisation on their organisation and industry. The survey showed that digitisation could bring substantial benefits to their organisation in terms of enhanced planning, asset utilisation and streamlining the processes. Digitisation was also seen as a mechanism for improved supply chain connectivity through enhanced visibility and better access to data. Improved customer service and interaction with other functional areas was also recognised as a key benefit by the respondents. Survey participants also reflected that digitisation could bring substantial benefits for future investment decisions, particularly in remote and regional areas, where network investment is critical for their economies, financial sustainability and workforce. Reduced human error, improved accountability, reduced waste and safer operations were also acknowledged as other potential outcomes. Overall, the high rate of positive sentiment among participants is an encouraging sign that organisations observe digitisation as a constructive catalyst, and hence, potentially reflecting on their knowledge of digitisation and/or openness or readiness to change.
- **Negative:** Few participants provided negative or concerned responses when asked about the future impacts of digitisation on their organisation and industry. Responses highlighted the following concerns:
    - Supporting industries such as truck and original equipment manufacturers could be placed under significant pressure to fulfil the ever-increasing digital needs of freight companies.
    - Outdated regulatory and operational frameworks could potentially impede the uptake of new technology in their industry.
    - Potential impacts of digitisation on the workforce during transition period. For example, progress towards digitisations and automation in the transport and freight industry (e.g. CAVs) could negatively impact HV driver availability, due to lack of career prospects.
- **Unsure, mixed view and not applicable:** Some respondents highlighted digital technologies could bring fundamental changes to the way they currently operate, but did not specify which functions and how. This perhaps could be an area of concern, showing that some of the players in the Australian transport and freight industry do not have a clear understanding on the disruptive impacts digital technologies and their implementation outcomes. Furthermore, some participants reflected a mixed view but emphasised on the importance of having a shared understanding and agreed role of government in such transition. Furthermore, a few participants did not observe any potential impact, mainly because of the nature of their operations and role in the transport and freight industry (e.g. advisory or lobbying groups). Studies such as this could be instrumental in providing the necessary background to such industry participants, and to ensure the value of digital technologies are harnessed appropriately across various domains.

Question 5: How to be prepared? The role of governments and industry

One of the objectives of industry consultation was to identify opportunities and areas to better prepare for wide scale acceptance and implementation of digital technologies across the transport and freight sector. Respondents provided very important insights, with their input ranging from the future role of government, capability building, to cultural and behavioural topics, with many of them closely intertwined (**Figure 23**).

Figure 23: Key areas for future preparedness

- **Vision-led role of government and regulatory mechanisms:** Participants' input around the role of government and regulatory aspects was extensive and diverse. An evident theme was around the leading responsibility of government in establishing a vision and addressing the barriers and challenges to digitisation. Promoting digitisation through appropriate incentive mechanisms was highlighted as another key area. Respondents emphasised on the critical role of policy and regulatory frameworks for a smooth embracement of digitisation. For example, outcome-based and risk-based legislation was identified as the right approach to incentivise the uptake of innovation and technology. However, government incentives for digitisation was also criticised by one respondent, saying that technology uptake should not be subsidised.

- **Research and capability building:** The next identified theme was around the need for further research and building digital capability. The topics covered under this thematic area were diverse, ranging from workforce development to the need for further research. A key area identified by the respondents was around workforce and knowledge development, through establishing expert teams and joint planning. The second area focused on the need for further research to better understand the various dimensions of digitisation in transport and freight, from conceptualisation to implementation and sustainable support. Respondents also highlighted that future digitisation research should involve investment in proof of concepts (PoCs) and piloting with robust use cases and transparent reporting of performance outcomes. One respondent also emphasised the importance of providing appropriate incentives to SMEs to invest in digitisation. The need to collaborate with international partners and benefit from their learnings was also identified as an area for building digital capability.

- **Collaboration and coordination:** This thematic area was focused on the need for further coordination and collaboration across both public and private domains. The need for further coordination and collaboration was recognised at two dimensions – between different levels of government **and** between government and industry. Furthermore, one respondent stated that while collaboration is key to successful digitisation, it should be reflected in all dimensions, e.g. from co-development, implementation and training. Respondents highlighted the need to involve all levels of government for digitisation to be successfully embraced. For example, consultation with local governments was highlighted to be essential, particularly if there are exchanges in data. One respondent stated:

> Collaboration is key to successfully digitising the supply chain in Australia, digitisation efforts need to be on a national scale to ensure standardisation and increase the likelihood of uptake.

- **Data standardisation:** Respondents identified that a key area to prepare the industry for uptake of digitisation is around establishing industry-wide accepted data collection, exchange and integrity frameworks and systems. It appears participants believe that centralisation of multiple data sources to a single or one-window system is an essential and preliminary step to prepare the industry for digitisation. One respondent emphasised the need to support data hubs and data exchange programs. A recent example of such initiative is the establishment of the National Freight Data Hub by the Australian Government (https://datahub.freightaustralia.gov.au/). To achieve this, some respondents highlighted that collaboration is essential to adopt agreed upon data standards and metrics.
- **A single national roadmap:** The need for a single nationally agreed roadmap and strategic plan to understand the future state of industry in the presence of digital disruptions was clearly recognised by several respondents. Governments and industry should work closely to gain an accurate understanding of what digitisation means for the transport and freight sector to develop a roadmap for successful and large-scale uptake of technology. Such an exercise should be supported by understanding the (cross) jurisdictional objectives and challenges.
- **Cultural and behavioural:** Finally, in terms of opportunities for preparedness, respondents identified an area that is associated with establishing a culture for change. Some respondents recommended the importance of socialising and sharing learning through future joint events and planning. It appeared that different parts of the industry have been developing and trialling different technological options, with the outcomes not necessarily shared widely. Furthermore, some respondents discussed the difference between acceptance and implementation of digitisation. For example, acceptance requires education and familiarisation of the industry with digital technologies and their associated benefits, while implementation is a longer-term exercise requiring standards, funding mechanisms and nationally accepted regulations.

Question 6: Open recommendations

In the final part of the industry consultation survey, an opportunity was provided to the participants to openly provide any suggestions, issues or ideas. Such open-ended questions allow respondents to freely express their views, regardless of the survey structure. It is important to note several participants did not participate in this question. In addition, given the open-ended nature of this question, it was difficult to identify specific thematic areas, which are shared among all participants. A summary of the key takeaways is provided.

Data remained a key area, with recommendations ranging from streamlining and standardising processes involved in collection and exchange of data, to maintaining the appropriate privacy protections. As freight management systems and processes become more automated and data-driven, their vulnerability to malicious and deliberate cyber attacks increase. Therefore, the need for resilient cyber-physical systems to avoid any supply chain disruption becomes more crucial. Interestingly, one respondent recommended that the outcomes of this study should inform the development of National Freight Data Hub.

Furthermore, the need for enhanced coordination and collaboration between different levels of government and industry was again highlighted as an important area. In particular, the role of local governments and the opportunity to capture data from the infrastructure they manage was also emphasised. Although connecting with local governments was identified as an opportunity area, it was emphasised that digitisation and data-focused efforts should be initiated, funded and led by the federal government, as it would be complex and costly to expand state-based systems to a national level.

Respondents also highlighted the need for appropriate education and upskilling programs for transforming the mindset of industry (e.g. operators) from today's traditional paper-based systems to digitally oriented ones. In addition, the applications of digital business models such as the sharing economy, MaaS and micro-mobility were identified as some pathways towards digitisation of the transport and freight sector.

Key takeaways

The diversity in participants' backgrounds and representing organisations provided a unique opportunity to capture important insights on how digitisation could be introduced, implemented and/or challenged by various industry stakeholders, and across functional areas and transport modes. From the overall analysis of questions presented to industry executives, the key takeaways can be narrowed down to the following areas:

Data as a double-edged sword: It was apparent that data was one of the core topics and concerns discussed by the industry participants. Access to reliable and quality data was identified as a catalyst for digital growth and innovation in the transport and freight sector, but also as a facilitating mechanism for improved infrastructure investment decisions and planning. However, it was evident that the majority of participants have meaningful concerns about lack of a nationally accepted system for the collection and exchange of data. This issue was further recognised in the freight sectors, mainly because of the cross-jurisdictional nature of freight operations. On the other hand, privacy protection issues were recognised by the participants as a prerequisite for streamlined and standardised data collection and exchange. Some respondents indicated that in the absence of such assurance instruments, industry's willingness to share data with government and other actors could diminish.

Government as the leader and connector: The second takeaway from the industry consultation was around the role of government in facilitating the journey towards digitisation. It was also highlighted that future efforts around capture and exchange of transport and freight data must be federally driven, but in consultation with states and local jurisdictions, as state-based systems are complex and expensive to expand nationally. Vision-based leadership from the government to establish a nationally accepted roadmap to conceptualise and support the adoption of digitisation in transport and freight was highlighted as a preliminary step. Surprisingly, while government funding was mentioned, it was not highlighted by the participants as a key issue or opportunity. This perhaps indicates that the transport and freight industry is expecting a connecting and enabling role from the government.

Positive sentiment: The majority of respondents shared an optimistic view towards digitisation and its potential impacts on their organisation and industry. It appears that respondents have already identified several opportunities to improve productivity through adoption of digitisation, including access to real-time and reliable data, which is essential for increased operational efficiency, asset utilisation and automation. This perhaps is a positive sign, revealing that the industry is already trialling the uptake of technology. On the other hand, this positive attitude presents an opportunity for the government to further influence and promote the adoption of digitisation across the sector.

Limitations

The industry consultation conducted in this study comes with some limitations, which opens avenues for future work. The sample size for this study comprises 27 executives from the transport and freight industry. However, it is important to note that the sample size does not allow for providing statistically significant analysis. Therefore, the analysis presented in this work is a combination of participants' reflection and researchers' qualitative analysis. Future work could empirically investigate the key areas identified in the present study using larger sample sizes and wider industry consultation. Furthermore, since this study was undertaken as a point in time, future work should look at longitudinal investigations to examine the changing view of industry on digitisation as technology uptake is being progressed.

Policy lessons

Policy lessons

The review conducted in this research identified key success factors for the deployment of digitisation solutions in each of the transport and freight sectors and component functions. In this section of the report, we also present the policy interventions that characterised the successful deployment of digitisation solutions in countries with high adoption of transport and technology solutions. One of the most notable aspects of mobility in these countries is how widespread their smart technologies were and the impact they had on productivity, efficiency and the quality of life of people in terms of ease of travel, reduced congestion, and improved safety and reliability of transport services. These success stories provide a unique insight into these countries' remarkable journeys in smart mobility and digitisation of transport and freight and the factors which contributed to their success (**Figure 24**). Although non-policy factors such as geographical constraints, cultural and political issues played some role, it was ultimately their national policies that made them successful in transport and mobility innovations.

Figure 24: Policy principles for best practice transport and freight digitisation
Source: Authors

The recurring policy themes in these leading countries are summarised below. These policy principles apply both to countries embarking on new transport and freight digitisation projects, as well as developed economies looking to make the most of existing assets.

1. **National vision**. Countries such as South Korea, Japan and Singapore have all demonstrated a national-level commitment to smart mobility and digitisation solutions.

From the outset, their governments articulated and owned a clear vision for technology deployment and linked it to national information technology policies and long-term strategies for improving productivity, safety and the quality of life for their citizens. Governments in these countries also demonstrated strong leadership in convening relevant stakeholders and spearheading implementation. These countries featured strong government leadership in crafting a clearly articulated transport digitalisation vision, setting a national agenda, convening relevant stakeholders, and spearheading implementation. For example, in Japan, transportation policy is set at a national level by the Ministry of Land, Infrastructure, Transport and Tourism, supported by the National Police Agency and the Ministry of Internal Affairs and Communication. In Singapore, all modes of transportation administration, and transport digitalisation policy, are under the control of a single agency, the Land Transport Authority. From the start of their smart mobility plan, this allowed Singapore to integrate and synchronise its application of transport technologies across roadways and public transportation, including buses and rail. Similarly, South Korea charged the Ministry of Construction and Transportation with spearheading the country's transport innovations program.

2. **Commitment to funding**. As a percentage of GDP, South Korea and Japan each invested more than twice as much in their digitisation solutions and smart mobility than the US. Not surprisingly, this level of annual spending (around 0.016% of GDP) allowed South Korea to provide 100% coverage of ITS on all expressways (around 4,000 km) and 20% coverage on national roads (2,500 km out of 13,000 km). The scale of investment was substantial. South Korea's National Smart Mobility Plan 21 was initiated in 2007 and provided investments exceeding US$3.2 billion between 2007 and 2020. This was equivalent to an average of US$230 million annually over the 14-year period. Japan also invested ¥64 billion in smart mobility in 2007-08 and ¥63.1 billion in 2008-09 financial years. This was the equivalent of about US$690 million annually. Examples of successful smart mobility projects in South Korea are Seoul's public transportation card system (T-Money) and Anyang's Anyang Traffic Information Centre. For these systems to be successful, Seoul continued to invest in the infrastructure for public transport to facilitate the usage of T-Money, and as a result, T-Money had early adoption rates faster than expected. Seoul allocated a large budget to construct more infrastructure even after adopting the revised public transportation cards system, which resulted in more services and benefits for citizens.

3. **Partnership and collaboration**. The public and private sectors in leading countries played an important role in co-developing platforms that enabled government, industry, academic and professional associations to collaborate on developments at both local and national levels. The common practice for C-ITS development in these countries involves collaboration among related agencies and the R&D sector. For example, a collaboration between Nanyang Technological University and the private sector was instrumental in the development of the Smart Mobility 2030 strategic plan which was launched in 2014. This collaboration initiated a number of ensuing projects which were launched in 2016. Similarly in Korea, the Ministry of Land, Infrastructure and Transport collaborated with the private sector on the C-ITS Master Plan, which was launched in South Korea in 2013. The Daejeon-Sejong expressway was also initiated in 2014 as a result of this collaboration. Another example is the public-private ITS cooperation formed as part of the ITS Promotion Guidelines, released in 2004 in Japan. This collaboration resulted in C-ITS projects which were launched in 2014. In addition, the Ministry of Transport of the People's Republic of China also collaborated with the Ministry of Industry and Information Technology and the private sector as part of the government's initiative to drive the development of autonomous car testing, which started in 2017.

4. **Facilitating private investment and value-add services**. Leading countries were all successful at facilitating private investment, an important consideration in forging public-private partnerships within their countries and internationally. These countries viewed their investments as creating a platform through which the private sector could develop value-

added products and services. These countries considered the involvement of the private sector essential in infrastructure investment, delivery, and management. The private sector investment generally constitutes a small proportion of the total infrastructure investment because the costs and risks faced by the investors are high, particularly in emerging markets and developing economies where the economic, institutional and financial conditions are weaker and less predictable. Success stories of facilitation of private investment includes the San Francisco Bay Area Rapid Transit (BART), which adopted a transit-oriented development policy to increase ridership, secure annual revenue, reduce taxpayer subsidies, and improve connections with the community. As a result, the San Francisco BART is currently engaged in 18 TOD projects at its rail stations, representing over US$2.7 billion in private investment and is in negotiations for another seven projects valued at US$1.15 billion. TODs have a proven record of generating significant funds that can be reinvested in public transport. As well as providing ongoing sources of revenue for transport services and infrastructure investment, TODs have also been shown to encourage public transport patronage and reduce road congestion by encouraging people to walk and ride public transport instead of driving.

5. **Standardisation**. Leading countries developed national digital architectures, which provided the basis for interoperable transport and freight digitisation applications. This architecture assisted in the delivery of consistent, cohesive and cost-efficient services to citizens such as establishing common standards for electronic toll collection (ETC) in Japan. Common ETC standards encouraged high market uptake of on-board devices in more than 70% of vehicles in Japan. In Singapore, the single national standard of ETC also facilitated the implementation of city-wide congestion charging scheme from as early as 1998. In Japan, the government has also been involved in research on 172 standards and services in nine different fields, cooperating with the relevant ministries and agencies in conjunction with the private sector since 1999.

6. **Cybersecurity and data protection**. Technology-enabled smart mobility and digitisation solutions are vulnerable to cyber attacks in many ways. These can include advanced persistent threats; asset, data and identity theft; hijacking of devices; hacker-in-the middle attacks where a hacker can interrupt communications between two devices; distributed denial of service; ransomware and physical disruptions. In order to keep digital assets protected, leading countries have implemented cybersecurity programs that allow for data encryption, constant security monitoring, and security support platforms. Other best practice approaches include conducting thorough investigations about new technologies before implementing them; starting with small-scale and proof-of-concept initiatives and testing if they can withstand simulated cyber attacks; creation of a dedicated cybersecurity team that is well-trained and provided with the necessary support platforms; and having backup plans and proven risk mitigation plans and systems in place to be able to recover quickly in case the digital assets fall victim to a cyber attack.

7. **Research and development, and education**. Leading countries recognised from early stages that transport and freight digitisation will not reach critical mass unless they commit to funding large-scale research and demonstration projects. For example, the 2025 ITS vision, announced by the Japanese Cabinet in June 2007, articulated policies on R&D and set a goal that: ‘By 2025, ITS will have been constructed that integrate vehicles, pedestrians, roads, and communities; and that has made traffic smoother, and almost eliminated all fatal traffic accidents’. OECD data shows that leading countries in transport and freight digitisation have also put in place strategies to support translational research through direct involvement of industry and the private sector to collaborate on research that is directly relevant to industry needs and requirements.

8. **Innovation and competition**. This policy principle recognises the role of the private sector in developing and making available to governments and citizens innovations and technologies to improve their lives. Examples include alignment between the transport and telecommunications industries, where digitisation was recognised as being inseparable

from wireless technologies (for cooperative mobility applications) and high-speed networks (for video transmission). Some of the best examples are from Finland. The country has a range of programs that consider a holistic approach to innovation. These include the Green Growth, Innovative Cities (INKA), Witty City, Electric Vehicles and Systems programs. The INKA program is reported to have the most vital linkage to the government policy level. The INKA program also constitutes the main innovation policy context of the Finnish government focusing on the transition to smart transport systems in city environments.

9. **Planning for deployment.** A significant portion of the funding available to leading countries was allocated to supporting digitisation and technology development, test-beds and POC demonstrations as a precursor to widespread deployment. This approach also helped inform and educate their citizens about the tangible benefits of smart technologies in transport. For example, Singapore's February 2020 budget included SGD$6 million (US$4.3 million) to support autonomous vehicle test-beds. Another example of deliberate interventions to support deployment is demonstrated by the data sharing coordinated approach in Netherlands. Policies on data sharing were initiated at all levels of government – municipal, regional, and national. A coordinated approach, whereby national governments provided the broader infrastructure to develop customised local solutions, helped to mobilise large-scale efforts and resources. Their approach to data sharing and MaaS implementation demonstrates their commitment. Seven national MaaS pilot projects were established with different regions where each pilot focused on a different use case and policy goal. For example, one trial focused on commuter traffic in Amsterdam, another considered cross-border transport in Limburg, and a third focused on carbon-neutral travel in Eindhoven. The data from the seven national apps will be made available in a learning environment dataspace to help researchers and practitioners optimise the total mobility system. Another demonstration of their commitment to innovation and testing new solutions, the Dutch Ministry of Infrastructure and Water Management initiated a blockchain challenge in 2019 to explore new solutions to exchanging sensitive data on MaaS pilots. The initiative received considerable interest for testing including a Sony-backed project to develop a blockchain common database to record and share anonymised large-scale movement history and revenue allocation for MaaS.

10. **Performance-based solutions.** Countries leading in transport and freight digitisation recognised the need to move from a political or state-based system of allocating transport investment to one that uses performance and cost-benefit analysis (CBA) as the basis for investment decisions. Transport and freight digitisation promotes this principle by providing quality data needed to make sound performance-based investment decisions. The private sector can also use this data to provide value-added services. These countries also recognised digitisation in transport and freight as a 'force multiplier' presented in earlier sections of this report. Decision-makers in these countries were informed to recognise the importance and high BCRs of these digitisation solutions.

Recommendations

Recommendations

The policy interventions and success factors identified in this review, and the stakeholder consultations feedback provide direction for a number of recommendations to support wider adoption of transport and freight digitisation in Australia. These recommendations are aimed enhancing support for the digitisation ecosystem – including policies, regulations and infrastructure requirements, which are needed for a rapid digital transformation in these sectors. Where relevant, side bars are used to present examples or further relevant information about each recommendation.

Develop a national vision for smart mobility

Countries that are leading in best practice transport and freight digitisation have put in place national multimodal smart mobility strategies as part of their smart nation visions. Examples of countries that have developed such strategies include Singapore, Japan and Korea.

In Australia, the important role of digital technologies in boosting the economy is recognised through the Digital Economy Strategy 2030 which was released in May 2021. The strategy aims to ensure that Australia becomes a leading digital economy and society by 2030. It also brings together policies and programs across government including, in the freight and transport technology space, the National Freight and Supply Chain Strategy and National Policy Framework for Land Transport Technologies and associated Action Plan, which are overseen by infrastructure and transport ministers across Australia.

Under the Digital Economy Strategy umbrella, there is an opportunity to develop a more comprehensive national vision for smart mobility that also includes public transport, freight, rail, aviation, maritime and shipping, and active transport covering key pillars aligned with digital economy, digital society and digital government.

The national vision for smart mobility would need to be developed in consultation with key stakeholders from industry, community, research and academia, and government agencies at all levels. This will require a targeted effort over the next few years to enable productivity gains to be achieved by 2030. Consideration can be given to holding a summit of industry, peak bodies and government to drive a rapid delivery of the strategy to meet the goal of being a leading digital nation by 2030.

Singapore's national vision

Singapore's Smart Nation Program was launched in 2014 to harness technology use in all aspects of people's lives. The program recognised technology and digitalisation as key enablers for transforming a number of key domains including health, transport, urban solutions, finance, and education.

Smart Nation Singapore included specific initiatives for smart urban mobility projects that leveraged data and digital technologies, including AI and autonomous vehicles, to further enhance the public transport commute. The urban transport program was also strongly aligned with building a Smart Nation Sensor platform. This digital platform provides Singapore with an integrated nationwide solution for data integration and use in improving municipal services, nation-level operations, planning and security.

It is noteworthy that Singapore has undergone two previous whole-of-nation digital transformations. First, with their National Computerisation program from the 1980s to early-1990s, an initiative that was aimed at transforming Singapore into a regional centre for computer software development and services. The second transformation was part of the growth of the info-communications industry from the mid-1990s to early-2010s, with a number of initiatives and programs that aimed to develop Singapore as a hyper-networked, global hub for services.

Set new policies for smart mobility in the digital age and align digital transport initiatives with national development strategy

Regulation plays an important role in either driving or stifling digitalisation. Removing the barriers to widespread transport and freight innovations requires setting new tech regulations and policies. It also requires harmonisation of existing and new policies related to legal frameworks for use and operationalisation of digital solutions and technologies in transport and freight. Similarly, further harmonisation of private mobility and freight transport in terms of policy, investment, and legislation would be required.

Specifically, the fast pace of technology developments and scientific advances in fields such as AI and autonomous driving systems calls for policy innovations and agile policy making processes and institutions. In particular, policies for interoperability of digital infrastructure are needed to avoid creation of monopolies in the supply of digital platforms, which requires regulations to manage such risks and ensure healthy competition.

New policies should also recognise the role of regulators in developing digital sector policies to make digital enablers universal, affordable, open, and safe, through securing market competition and promoting open government data. Policies are also needed to ensure online data privacy and cybersecurity. The aim would be to secure the data subjects' rights and regulate the obligations of the data processers and aggregators while collecting, processing, and using personal data. An effective example of this is the Consumer Data Right framework (Australian Government, 2021).

New policies also need to manage the growing risks of concentration, inequality, and control that can undermine the promised shared prosperity. When the enabling digital platforms deliver scale economies, but without a competitive environment, the outcome could be excessive concentration and monopolies. When tasks are fast and automated but workers' skills are not continuously upgraded, the outcome could be greater inequality.

Support translational research and testing of promising new technologies

Countries with high levels of transport and freight digitisation support R&D and play an entrepreneurial role in researching and testing promising new digital platforms and technologies. The R&D does not only focus on new technologies but also on their human complements and adaptation to local context. The R&D can also include support for innovation through monitoring global trends and adopting emerging digital technologies that are already available globally, and testing and adapting them to the local context before scaling up.

> **R&D commercialisation**
>
> Although Australia ranks near the top of OECD countries for research excellence, its research ecosystem is much less effective at collaboration between industry and researchers.
>
> R&D and innovation have an important role to play in delivery of new technologies, especially those for Australian conditions. Accordingly, future reviews of R&D and innovation programs should be mindful of the specific needs of transport digitisation, to ensure the benefits are enabled.

Industry and government working together – and acting as innovative and risk-taking activists for digitalisation – will be beneficial to encourage sourcing these emerging technologies, supporting early adopters, and developing the complementary policies and test-beds for effective absorption and localisation.

According to the latest published OECD Science, Technology and Industry Scoreboard (The Digital Transformation), Australia ranked amongst the top of OECD countries for research excellence. However, it ranked lowest in terms of engagement between industry and academia. The study found that only 3% of innovating SMEs and only 7% of large firms in Australia have developed their innovations in collaboration with universities or research institutions. This is much lower than the OECD average of 13% for innovating SMEs and 31% of innovating large firms in OECD countries (OECD, 2017). A number of factors contributed to these differences including degree of alignment of business and academic research expectations; ability of businesses to absorb research outcomes within their organisations; and strength of ties and history of collaboration between the business and research institutions.

Finally, a lack of harmonised methodology for CBA of disruptive technologies in transport and freight hampers the deployment of innovative solutions and may encourage the retention of more traditional solutions that are less beneficial to the public. More research is needed in this area as cost-benefit analyses have a major effect on future transport planning and provides the evidence base for supporting future investments in areas that have higher benefits to the community. There is scope for this to also be considered in the Australian Transport Assessment Planning Guidelines as part of future reviews of transport costs-benefit analyses.

Investment in backbone digitisation infrastructure should be considered with transport digitisation

National digitisation policies should aim to accelerate the rollout of backbone infrastructure including IoT sensors as well as digital platforms for data collection, sensor fusion and performance measurement. Specifically, investment outside of populated areas, but on key freight routes, is something governments and business should consider. Opportunities for public–private partnerships and cooperation between government and industry can help speed up rollout, particularly in regional areas. In such partnerships, governments can provide comprehensive national-level policies and frameworks for engaging stakeholders and guarding national and consumer interests.

Experience from countries with high levels of transport and freight digitisation shows that successful technology diffusion requires policies that address both the supply and demand-sides of backbone digital infrastructure. Supply-side policies focus on promoting network infrastructure for service delivery, while demand-side policies aim to raise awareness and encourage adoption of services. Promoting national build-out solutions will likely require governments to pursue multiple strategies depending on each state's circumstances. Due to high capital costs and maintenance, governments should be open-minded to considering ways to better enable infrastructure sharing where there is clear evidence that this will lead to better outcomes for consumers and business. This would include consideration of any legislative or regulatory barriers that might hinder sharing.

To improve the rollout of supporting digital infrastructure, leading countries have also provided the private sector with incentives to encourage infrastructure development in regional areas and in disadvantaged communities.

Commitment to investment

Leading countries in transport and freight digitisation have not only developed explicit national strategies for smart mobility – they have also invested heavily in it.

South Korea's National Smart Mobility Plan 21, initiated in 2007, provided investments exceeding US$3.2 billion between 2007 and 2020. This was equivalent to an average of US$230 million annually over the 14-year period.

Japan also invested ¥64 billion in smart mobility in 2007-08 and ¥63.1 billion in 2008-09 financial years. This was the equivalent of about US$690 million annually.

As a percentage of GDP, South Korea and Japan each invested more than twice as much in smart mobility solutions than the United States over the time period 2007-10 (ITIF, 2010).

Invest in human, organisational and institutional learning and capacity building across all sectors, to secure digital dividends and inclusion

Stakeholders in leading countries in transport and freight digitisation prioritise investment in human and institutional learning across all sectors. This includes substantial investment to implement organisational changes, process innovations, and other intangible digital assets (such as digital data and content) to realise the promise of digital dividends. These investments would be required at all levels of government and industry including SMEs. The capacity building would involve changes in skills, cross-sector partnerships, and leadership and managerial practices.

Working with the relevant stakeholders, governments at all levels can play a critical role in ensuring the wide and effective diffusion of digital technologies among lagging sectors and disadvantaged communities.

Bridging digital divide

Without societal, government and industry intervention, the risk of digital divide grows and further reinforces inequalities.

Governments can counter these divides through engaging different stakeholders to provide affordable access to digital infrastructure and investment in universal digital literacy and informational capabilities.

This requires piloting, trials and experimentation of technology solutions and assessing their impacts. It also demands that governments create the enabling environment to bridge the digital divide. In leading such efforts, government should work with civil society and community organisations, local government, business associations, universities, and philanthropic organisations to put in place relevant professional development and educational programs.

Adoption of new technologies by SMEs involves significant risks, learning, change management, and capability development. SMEs thus need support programs for adopting new digital technologies and for learning to transform their businesses and practices. Improving digital literacy in the short term can be achieved through various mechanisms of upskilling the existing workforce, long-term approaches must be nationally prioritised and aimed at digitally training the next generation of transport and freight workforce. Governments, industry, academia and peak bodies can provide support for learning and professional development programs to promote the adoption of new wave digital technologies among SMEs, including training for business development services.

Undertake feasibility studies of statewide integrated smart mobility operations centres

The capabilities of most existing TMCs present barriers to the management and control of multimodal smart transport networks. Digitisation solutions enable the sharing of information to help decision-makers optimise the utilisation of multimodal transport networks. Achieving this operational efficiency, however, will require a more integrated approach to interoperability that considers all modes of transport and applications that include tech-enabled integrated corridor management, multimodal transport systems management and operations, proactive traffic management, and CAVs.

Consideration should be given in smart mobility strategies to implement a TMC of the future in each state. The role of this centre will be to manage network performance in a more proactive manner. These centres would be staffed on a 24/7 basis and tasked to look after all state roads and transportation networks through advanced communications, networks of sensors and CCTV cameras, and IoT deployments.

Another potential dimension of the smart mobility operations and management centre is to transition today’s TMCs into statewide multimodal command centres These centres would create operational efficiencies in monitoring, operating, and managing a state’s transport assets including smart motorways, telecommunication systems, public safety and crime prevention systems, and multimodal transportation systems. Integrated decision support tools would also be developed to enable real-time information sharing among different functional areas.

While such a concept maybe challenging from an institutional and operational perspective, the potential benefits will provide significant performance efficiencies and productivity gains as was demonstrated in a number of case studies presented in this report.

Rio Operations Centre

The Rio Operations Centre was established to control the city's daily operations, integrating several departments involved in Rio's routine, and to manage crisis and emergency situations.

The motivation for the establishment of the centre was the need to respond to severe storms that cause flooding and impact the mostly low income settlements that are located on the high slopes surrounding the metropolis and are prone to devastating landslides. Following a vicious storm in 2010, Rio de Janeiro decided to create the centre that operates 24 hours a day, staffed by officials from 30 city departments representing multimodal transport and emergency services.

This centre has become a global model showing the benefits that can be derived from collaboration, alignment and data sharing across city divisions. The centre has had many other benefits including reducing traffic congestion and emergency response times. It also provides citizens with advance warning about traffic congestion and accidents and recommendations for route redirection in cases of emergencies and accidents.

Develop agreed standards and interoperability to improve data sharing and benefits of transport digitisation

The development cycle of innovative transport and freight digitisation is much shorter than the policy cycle. This is due to the rapid advances in technologies and scientific breakthroughs which leaves regulatory frameworks often lagging behind. This can lead to technical fragmentation and interoperability issues within countries and across countries. Through the sharing of data, services and information, the overall cost of providing digital solutions can be reduced and will particularly enhance the ability of the private sector to operate effectively.

In Australia, a focused effort to speed up development and implementation of regulations and enabling environments is desired. For example, regulations will play an important role in realising the potential benefits of advanced driver-assistance systems, particularly technologies used for higher levels of vehicle automation which are needed to pave the way for , deployment of autonomous vehicles.

Companies, governments and public entities should also be encouraged to provide user and other data collected on the use of public spaces and infrastructure, wherever it is available (ensuring that the privacy of the public is protected) so that users, agencies and third-party apps, operators, developers and innovators can access it to develop innovative solutions. Only by making the big data ‘open’ will third parties be able to integrate it into their systems and establish truly ‘cross-infrastructure’ integrated mobility systems.

Finally, security and privacy concerns could become potential barriers to the deployment of big data, IoT, and AI solutions in transport and freight. The applications need to be implemented using viable business cases that require consistent standards and regulations on liability and the highest levels of security for personal data. Similar concerns surround liability issues related to technology use. For example, highly automated or autonomous vehicles that act on behalf of the driver or override the driver’s decision introduce new challenges. Given the complexities surrounding these issues, further work in relevant fora such as Infrastructure and Transport Ministers’ Meeting and National Transport Commission would need to continue.

Standards and scalability

Disruptive technologies depend on the availability of an information and communication technology policy, which enables the systems that constitute the core of digital infrastructure.

The capability to deliver new solutions on a large scale requires new operating models. These will need to be developed to allow for effective collaboration between stakeholders as well as the public transport and private operators and individual mobility providers to co-deliver sustainable mobility and transport systems.

Urban and regional institutions will need to be equipped with the strategic capacity to transform and develop stable operational frameworks for tech-enabled mobility solutions, which will require innovative approaches to cross-sectoral planning and the shared use of embedded physical and technical infrastructure.

Future directions

Future directions

The findings from this study provide opportunities to highlight future directions targeting research to accelerate the adoption of transport and freight digitisation in Australia.

Undertake research to address data gaps

This study identified key data gaps that would need to be addressed in future studies to improve the accuracy and relevance of results. For example, one of the important data gaps is the level of spending on transport and freight digitisation as percentage of a country's GDP. These statistics are not only challenging to find, because such costs are usually included as part of infrastructure projects and may not be easily identified, but also because the cost of deployment can be substantially different between countries due to a variety of factors. In countries where labour costs are higher, for example, the same budget could deliver varying levels of transport and freight digitisation in different countries. Future research should explore methodologies for identifying and documenting such costs in a manner that makes it possible to undertake international comparative evaluations.

Develop a transdisciplinary smart mobility research agenda

As outlined in the recommendations section, and identified by stakeholders during the consultations, substantial benefits would be realised by adopting of a national smart mobility strategy. The strategy would be developed through extensive stakeholder consultation and linked to the UN Sustainable Development Goals as many other countries are doing (**Figure 25**). Such a linkage would be important to ensure alignment with international directions in decarbonising mobility, improving safety and accessibility, optimising supply chains, and increasing employability and social benefits resulting from transport activities.

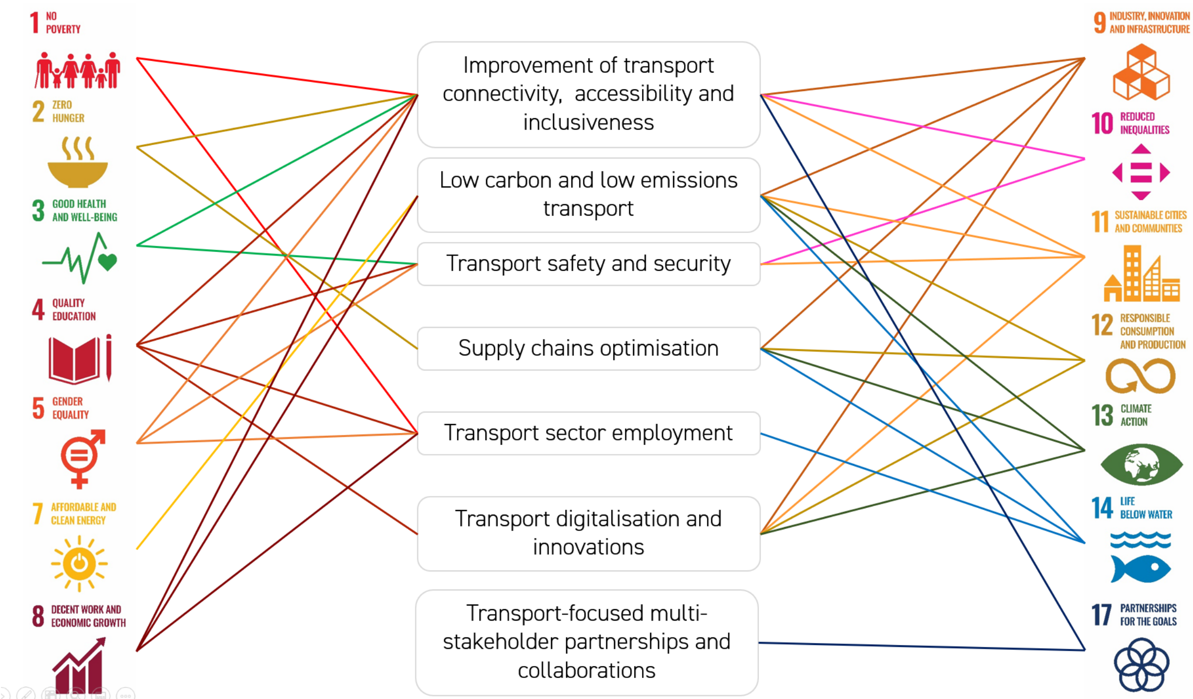


Figure 25: Alignment of national transport policies with sustainable development goals
Source: Adapted from ITF(2021a)

Central to the success of transport and freight digitisation strategy is rigorous research that meets Australia's transport challenges. Urban and regional areas are expected to achieve big gains through well-planned policy implementations and smart thinking on urban transport. To deliver substantial improvements in mobility, major policy, behavioural and technological changes would be required to achieve desired outcomes including increased productivity gains.

The establishment of a research agenda on smart mobility presents an opportunity to enhance support for research and innovation by building on existing success in transport research and intellectual capital. A thriving research agenda represents a major investment in the future of transport and freight digitisation, and would also provide a distinctive trajectory and direction for students, researchers and industry practitioners.

Establishment of a research agenda will need to be guided by the national strategy and industry needs and be based on a comprehensive consultation process. In this section, we present a research framework from 2019 that identified high-level research needs to enable successful deployment and integration of smart mobility solutions in Australia. The framework articulates a vision for smart mobility, maps the landscape of research themes and identifies the research gaps that need to be bridged to enable successful deployment. This framework draws on an environmental scan of the current status of smart mobility research and discussions and engagement with academics and industry stakeholders completed in 2019. This framework could serve as a starting point and would allow for an objective analysis of the current challenges and opportunities, areas where there is general agreement that fundamental research is lacking, and highlight new research opportunities available through new technologies.

Soliciting the insights and judgements of researchers and industry specialists also allowed for more insights. It also helped to map the areas where the stakeholders believed insufficient work has been done, and where more focused research is needed. It also allowed for identifying those areas that are likely to become important in the future and where research is needed to support their development **(Figure 26)**. This framework includes research programs which would investigate travel demand in the age of connected mobility; new methods to provide travel supply including autonomous shared mobility and on-demand car and ride-sharing; and investigations of long-term impacts on mobility, energy, urban form, sustainability and quality of life. The research agenda also includes strategic research programs in smart mobility governance and opportunities for improving urban and regional transport. The mapping in **Figure 26** demonstrates the wide range of ideas that have potential to deliver smart mobility, including options for electrification of road travel. The research framework includes studies which aim to understand:

Current situation and trends. This includes an assessment of the current situation and best practices in deployment of smart mobility and the new options for reducing the carbon footprint of transport with a particular focus on the opportunities available through disruptive technologies, shared car ownership and on-demand access to public transport and new mobility options. It also includes identification of emerging or anticipated future trends in urban mobility with a particular focus on the role of autonomous on-demand shared mobility solutions. While it is important that comprehensive environmental scans are conducted and a synthesis of published research is undertaken to identify gaps, it is also recognised that using the literature reviews as an extrapolation method has some limitations and will provide a limited insight into the trajectory of research in smart mobility. In these studies, it becomes important to solicit the insights of stakeholders through interviews, workshops, surveys and questionnaires on issues affecting their short to long-term transport operations and planning.

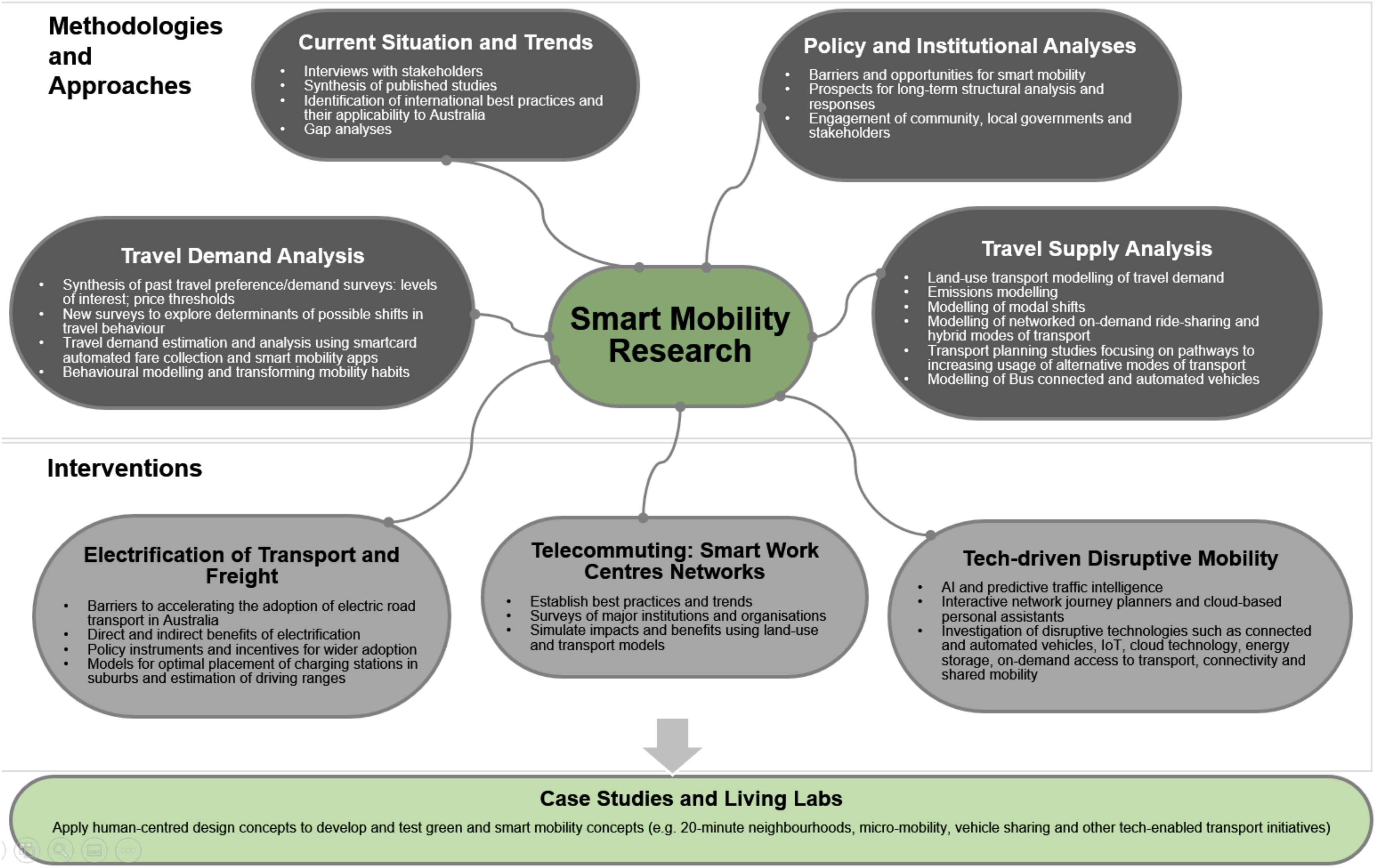


Figure 26: Example of a transdisciplinary smart mobility research framework

Policy and institutional analyses. This includes assessment of the barriers and opportunities arising from smart mobility solutions. The analyses should include an evaluation of the current regulatory frameworks, pathways to developing outcome-focused research, regulations under uncertainty, public expectations and acceptance of technology-driven mobility solutions, the future role of government agencies in managing the transport network under scenarios of shared autonomous mobility, and enhancing engagement with the community, local governments and other stakeholders. An important focus under these category of studies is also development of new urban governance systems to guide the creation of smart mobility innovations, corporate social responsibility, internet-enabled multi-stakeholder communication, and new modes of community engagement to plan pathways for deployment of ubiquitous smart mobility solutions. These efforts would be directed towards developing and evaluating new models and processes by which social, design and technological innovation can be more effectively delivered into the planning of smart mobility.

Travel demand analysis. This includes analysis of existing household travel surveys to define travel behaviour (e.g. trip generation, destination choice and mode choice for households), the conduct of new studies to understand the drivers for travel demand in the age of shared and connected mobility, and surveys to establish the determinants of shifts in travel behaviour from private vehicles to new mobility solutions. It also includes stated preference experiments to explore opportunities for changes in travel behaviour (trip frequency, destination and mode choices) to explore determinants of shifts in travel behaviour. Other studies that would need to be completed under this framework include travel demand estimation and analysis using predictive analytics, ML tools, and data mining of new sources of information from mobile use, smartcard automated fare collection and crowdsourced data to uncover behavioural patterns using sophisticated modelling and analytics tools. Travel demand studies would also need to include projects that examine the land-use transport interactions and their influence on the demand for travel modes under variable scenarios of supply of and service patterns, especially those related to digitisation, shared mobility and future autonomous vehicle applications such as first and last kilometre travel solutions.

Travel supply analysis. This should include studies into the modelling of land-use transport interaction, demand for travel and mode splits under different scenarios of digitisation levels, infrastructure supply, including walking and cycling infrastructure, EV charging networks and networked public transport service patterns. The modelling tools should allow for evaluating the impacts at a regional level (macro models); precinct level (meso models) and operational level (e.g. micro and increasingly sophisticated nano behavioural models). The application of these tools will allow for investigations of modal shifts, and the impacts of smart mobility intervention measures including their benefits in reducing emissions and social and economic costs of current levels of car-dependence. The travel supply analysis research should also look into transport planning and modelling studies focusing on pathways to increasing usage of transport and freight digitisation. The modelling tools can also serve as decision support systems for investment in smart mobility and would be valuable for assessment of the feasibility and cost-effectiveness of the proposed interventions, and assess a portfolio of investment options to encourage greater adoption of new tech-enabled mobility solutions.

Prospects for intervention. A large number of interventions are potentially available for decision-makers including transport and freight smart mobility interventions, telecommuting, electrification of road transport as examples. There is already considerable research and momentum around network management, teleworking and ITS interventions, but probably the area where important research is needed going forward is in disruptive mobility which includes collaborative shared mobility, autonomous vehicles and digital innovations. In these areas, more research is needed to address the following issues particularly about autonomous vehicles:

- Will they reduce or increase congestion?
- How will they impact total VKT?
- Will they increase or decrease urban sprawl?
- How will they impact urban form?
- Will they induce more demand for travel?
- What impact will they have on parking?
- Will they reduce or increase emissions?
- How will they impact car ownership?

Case studies and living laboratories. Research into smart mobility solutions and interventions should also include opportunities for creation of case studies and pilots in living labs. For example, a number of universities in the US have established off-road test-beds for testing autonomous driving. These are especially relevant to assessment of road safety impacts. Equally important are trials on public roads to provide travellers and consumers with opportunities to witness the new mobility solutions, evaluate their experiences, and get a better understanding of the potential impacts and opportunities while also helping authorities to learn more about the solution and work towards its deployment.

Practical research routes to inform urban mobility policies

The high-level research framework described in this section is aimed at identifying some practical routes that can be used to steer transport policy on smart mobility. As the list of 'next big things' grows longer with the fast pace of breakthroughs and scientific advances, it is important that policy making provides a guiding vision to ensure that technology interventions, in particular, are well applied and focused on user needs, and that they address genuine and practical problems that promote sustainable cities.

Some of the key research routes that have been identified in previous research are relevant and valid for smart mobility policies. These include:

Establish long-term impacts of new technologies

The sweeping changes anticipated by disruptive mobility have at times inspired visions of a very different future, as well as a good deal of hype. To distinguish between the hype and reality, rigorous and extensive research must go beyond the immediate obvious impacts. An example is autonomous vehicles which seem to have captured people's imaginations over the past five years. While they are very likely to introduce some big benefits such as reducing traffic injuries and fatalities and free up people's time from the driving task, it is still not well understood how they will impact congestion and the total vehicle-kilometre-travelled per capita, and whether they are likely to replace or augment public transport, and their potential impacts on health and wellbeing. There are also concerns about over-extensive urban sprawl and also impacts on energy and land use. Recent research suggests that the current vehicle fleet could be reduced by up to 90% in urban areas when a shared network of driverless vehicles is introduced. It is not clear, though, whether they will induce new demand for travel given that travel time will become shorter because of fewer vehicles on the road, and because people would feel that travel time is no longer unproductive because they are free from the task of driving. It is hence important to undertake research that looks past the immediate benefits and investigate how these technologies are likely to impact urban living, demand for travel, and social cohesion in the long term.

Develop rigorous but flexible evaluation frameworks and tools

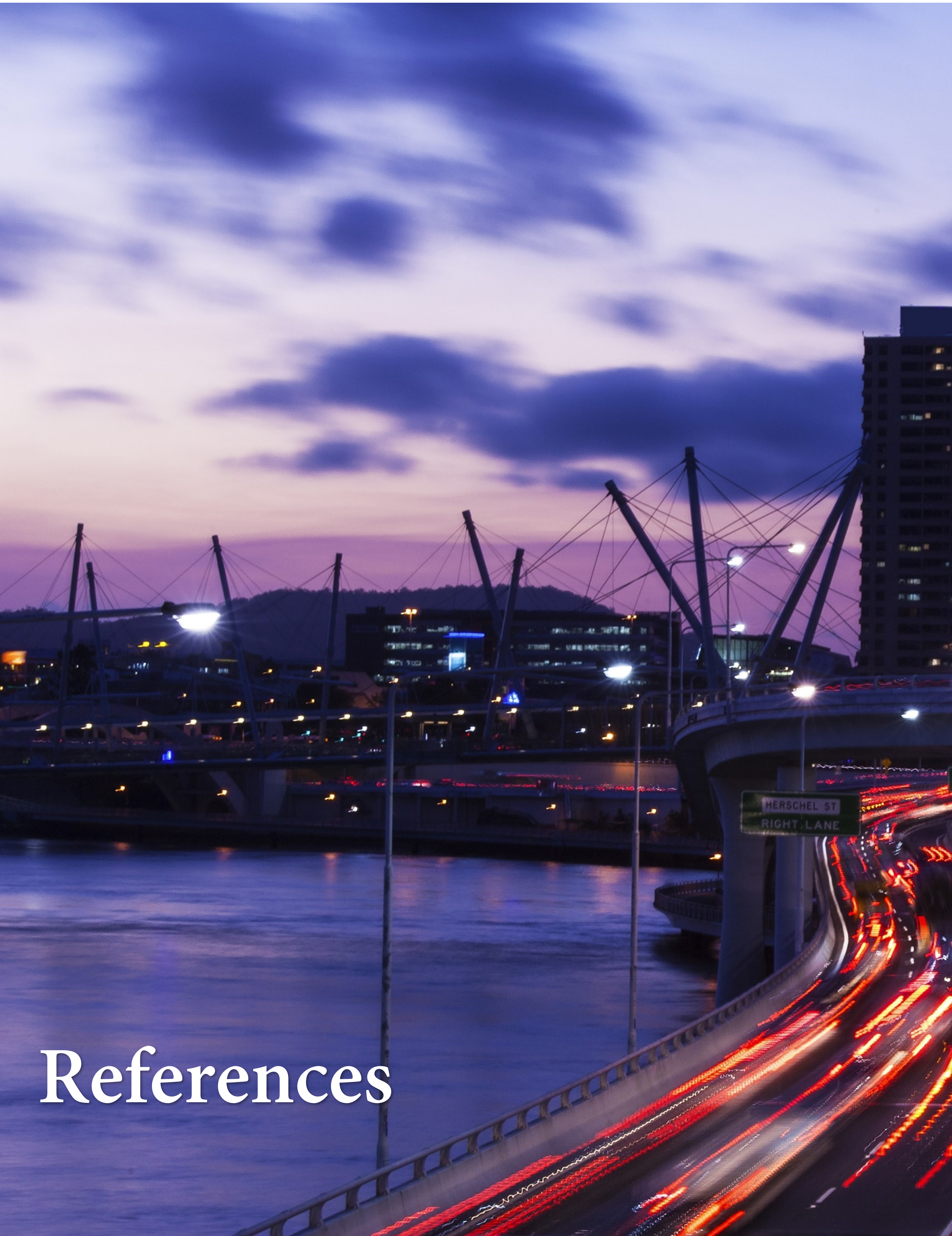
Given that some of the disruptive mobility solutions have not been tested and deployed yet, their impacts are probably best evaluated on test-beds or in simulations. The key advantage of using test-beds is that the ease of replicating reality and how consumers and drivers engage with and react to the technology. The limitation, however, is that they are usually small scale and can't capture wider long-term impacts on larger city networks. Agent-based simulations, properly calibrated and validated, provide a cost-effective solution to complement the test-bed evaluations, but these also have some limitation particularly in replicating behavioural issues. Further developments are also needed for decision making tools. The most commonly used method to evaluate transport projects today is the CBA. While this is effective in determining monetary value over a period of time, CBA does not consider other important factors in terms of how it will affect other facets of people's lives. This includes who exactly will benefit from the project, as well as who does not. Multi-criteria analysis is an improved evaluation tool compared to CBA as it analyses a broader set of criteria or policy objectives. However, this method is subjective and inconsistencies may arise. Other methods that offer improved evaluation techniques must be developed. These techniques should complement the CBA with risk assessment, as well as consideration of qualitative impacts on the general public.

Adapt governance systems and develop agile and outcome-focused regulations

Regulations will play a key role in the emergence and development of disruptive mobility solutions. They are also likely to be the biggest hurdle for their deployment. The regulators must adapt and rethink their approaches to avoid stifling the innovative uses of these technologies. Effective responses require an early and on-going dialogue between regulators, developers and the public in which regulators would create legal frameworks that are flexible but robust. For example, with driverless vehicles, an important role for the regulators will be to limit physical risks especially those that might be posed during interim years when legacy fleets of cars would interact with autonomous vehicles. Given the fast pace of technological developments, regulators would need to rethink their roles and focus on achieving agreed outcomes rather than enforcement of codes and standards.

Facilitate and encourage active transport and public transport innovations

Some of the current mobility disruptions such as car-sharing and ride-sharing are already having an impact on jobs and there is concern that it may in the long run impact public transport, particularly bus services. There are a number of innovative public transport initiatives around the world such as on-demand bus services which so far have not been deployed in a scalable way. Adopting innovative solutions for bus transport, in particular, is crucial for moving towards a more sustainable future and will play an important role in bridging the gaps for first and last kilometre travel. Public transport must be efficient, attractive and of good quality to appeal to the general public, and its development must be part of a holistic solution that integrates public and active transport modes in a digitised ecosystem. Smart technologies and strategies that can support and increase the attractiveness and appeal of micro-mobility solutions such as e-bikes and e-scooters would also contribute to more sustainable mobility solutions.



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Appendix A – Case studies

Appendix A – Case studies

This appendix includes summaries of representative international case studies on transport and freight digitisation interventions and solutions.

Key road sector case studies

Project name	Functional area	Description
Ramp Signalling Operations Strategy, Department of Transport and Main Roads, Queensland, Australia	Managed Motorways	This project aimed to develop a Ramp Signalling Operations Strategy (OS) for use on the Pacific Motorway (M3) between Loganlea Road and Cornwall Street. The technical reference document was mainly targeted at TMR's Road Operations staff who had responsibility for the day-to-day operation of the ramps signals. The development of this document was required to guide and direct staff in the operation of the new state-of-the-art dynamic and coordinated ramp signalling system (i.e. HERO algorithm), which is being implemented on the M3. The strategy included an overview of ramp signalling; the ramp signalling control strategies; policies for ramp signalling operations; fault management and maintenance; mitigation of impacts on adjacent arterials; calibration guidelines; performance monitoring, evaluation and reporting; and media broadcasts and response to public queries.
ITS Strategy for Far North Queensland, Department of Transport and Main Roads, Queensland, Australia	Network management and control	The ITS Strategy Implementation Plan for the Far North Region identified the issues and challenges for the Region through examination of relevant data and consultation with key agencies and stakeholders. The strategy recognised the role of advanced transport technologies in addressing the safety, efficiency and mobility of road users across the region, and identified the type of ITS technologies required, and locations where these technologies are needed. The strategy included a phased implementation plan which resulted in the installation and operation of a number of ITS elements.
Advanced Signal Control Technologies in Florida	Adaptive traffic signal control	The Florida Department of Transportation (FDOT) has implemented Adaptive Signal Control Technologies (ASCT) on eight corridors in Florida to overcome the limitations of traditional signal systems in cases of changes in traffic demand, weather, incidents, etc. The main objectives of this project were to evaluate the implementation of proposed ASCT traffic operations at several arterial corridors in Florida, before and after the installation of specific ASCT, document the advantages and disadvantages of different approaches and implementations, and provide recommendations for statewide implementation of ASCT. The mobility and safety benefits of the ASCT implementation were assessed by comparing performance measures of time of the day (TOD) plans versus ASCT through field data collection. Two critical intersections were identified within each corridor and performance measures such as corridor travel time, intersection delay, major and minor street queues, turning movement etc. were collected. Crash data was also collected over a period of fifty-nine months for safety analysis. A Benefit-Cost analysis was conducted by monetising safety and mobility benefits. The summary field data were used to build regression models of performance measures as functions of site characteristics. Qualitative observations and institutional issues were obtained by interviewing local staff. Recommendations were made on the suitability of corridors for ASCT implementation, and guidelines were provided for effective field implementation. The results showed That ASCT led to an average overall reduction in travel time of 9.36%. ASCT was found to generally help increase major street throughput (6.96%) and reduce major street queues (15.57%). The minor street queues increased (16.98%) while the throughput remained almost the same (0.69%). The benefit-cost analysis revealed overall net positive monetized benefits (12.8 considering safety benefits (crash reduction etc.) and 5.4 without safety benefits).
AI-based traffic signal control system (Surtrac)	Advanced traffic signal control	Surtrac is an AI-based real-time traffic control system currently installed at 50 intersections in Pittsburgh, Pennsylvania (US). The system aims to optimise traffic flow and reduce delays using AI technologies. The system operates in a decentralised manner where each intersection operates independently servicing its own local traffic. Hence, each intersections re-plans its operations in real-time based on local traffic conditions. The system was found to cut travel times by 25% and reduce number of stops by 30%, idling time by 40% and resulted in a 20% reduction in emissions. Expansion is expected to 150 intersections in 2022.

Houston TranStar	Traveller information systems	The Houston TranStar was the first implementation in the US to combine the critical functions of transportation and emergency management under one roof. One of the most visible products of Houston TranStar operations centre is traveller information. Local internet and media outlets use the TranStar CCTV feeds, internet-based incident reporting and travel time reporting systems in their daily traffic functions. Also, traffic service organisations are housed in the Control Room of Houston TranStar. In 2016, the travel time savings attributed to TranStar's operation was estimated at more than 17.4 million vehicle-hours. This was estimated to be worth more than US$392 million in road user cost savings and an additional US$65 million (or more than 32 million gallons) in reduced fuel consumption. The total estimated benefits of TranStar operation in 2016 were more than US$457 million. Comparing the annualised TranStar operating cost estimate of US$30.9 million to the estimated annual benefit of US$457.8 million yielded an estimated benefit/cost ratio for Houston TranStar centre operation of 14.8 for 2016. In other words, for every dollar spent on Houston TranStar's operations, the region realised a benefit of US$14.80.
Emergency vehicle priority, Queensland	Traffic signal priority and pre-emption	Emergency Vehicle Priority (EVP) is a smart solution developed in a collaborative partnership between ITS solutions provider Transmax and the Queensland Government, including the Public Safety Business Agency (PSBA). Transmax developed new STREAMS functionalities specifically for EVP including dynamic interventions for minimal traffic impact, pedestrian clearance protection, live monitoring at traffic management centres, and user-configurable recovery algorithms. Early trials in Southport on the Gold Coast in 2013 saw the 20 EVP-enabled emergency response vehicles receiving more than 600 green traffic lights per week supporting in excess of 100 incidents per week. There were improvements in travel times of between 10-18% along major routes with improvements in response times, compared with the previous year. Today, EVP-equipped vehicles on the Gold Coast show travel time reductions of up to 26%. The EVP system has been fitted out across intersections in Bundaberg, Mackay, South East Queensland, Toowoomba and Townsville. Across Queensland, as at 30 June 2017, there were 1,892 EVP-enabled intersections, and 438 emergency vehicles fitted with the technology.
East-West Priority Corridor, Maryland	Traffic signal priority and pre-emption	The Maryland Department of Transportation Transit Administration collaborated with the Baltimore City Department of Transportation on the *East-West Priority Corridor* Project, which is multimodal transportation enhancement project which included Transit signal priority. The department installed transit signal priority throughout the entire bus fleet and nearly 50 intersections, allowing buses to communicate with traffic signals and improve travel times. The Project included the purchase and installation of transit signal priority infrastructure to be added to existing traffic signal controllers along the Project corridor. The benefits of this project included reduction in bus passenger travel times by 4.7 million hours over the evaluation period, resulted in bus crash reduction of 12%, and eliminated 266 crashes throughout analysis period with an overall benefit to cost ratio of 2.32.
The Monash Freeway Upgrade	Managed Motorways	In 2016, Infrastructure Australia added the Monash Freeway Upgrade Stage 2 project to the Infrastructure Priority List as a High Priority Project. The Monash Freeway is a critical transport link to Melbourne's south east and outer south east regions, carrying over 470,000 trips per day. It provides access to the growing Monash and Dandenong National Employment and Innovation Clusters (NEICs). The Monash Freeway Upgrade Stage 2 involved extending managed motorway technology with Lane Use Management System and variable messaging signs. The benefits of the project were primarily for users travelling from the outer south east of Melbourne to the key regional employment areas of the Monash and Dandenong. The stated BCR for the project was 4.6 (excluding wider economic benefits), with a net present value of A$1,871 million (7% real discount rate).

The M4 Smart Motorway Sydney	Managed Motorways	The M4 Smart Motorway introduced a smarter way of travelling the M4 by using real-time information, communication and traffic management tools to provide motorists with a safer, smoother and more reliable journey. The M4 Smart Motorway is the first smart motorway for NSW and will bring together intelligent traffic technologies in one place to maximise the performance of the motorway. The Smart Motorway project, which consists of approximately 47km of the M4 Motorway in Western Sydney was upgraded to enable the installation and operation of 'smart motorways' technology to enhance travel time and driver safety. The main benefits included travel time savings (US$2.4 billion net present value, 69% of benefits), travel time reliability improvements (US$0.8 billion, 23% of benefits), wider economic benefits (US$0.3 billion, 8% of benefits), and other benefits such as incident management and incident reductions. Benefit-cost ratio (BCR) of the project was 5.3
Gateway Upgrade Project, Brisbane, Australia	Managed Motorways	This is an integrated Motorway Management System including VMS; weigh-in-motion sites; vehicle loop detectors; variable speed limit / lane use signs; help telephones; CCTV cameras; road weather monitors; automatic number plate recognition systems; and ramp metering signals.
South East Busway, Brisbane, Australia	Network management and control, demand management	This included detailed design for the implementation of ITS including electronic signage, CCTV cameras, video incident detection, ramp metering, public address systems and tunnel and bus station facilities management systems. The project also included the provision of a Busway Operations Centre, Busway Management System control and Bus Operations and Passenger Information software.

Key public transport sector case studies

Project name	Functional area	Description
Rio de Janeiro Municipal Operations Centre, Brazil	Safety, security, enforcement and compliance; data management and fusion	The Rio de Janeiro Operations Centre (ROC) was launched in collaboration with IBM to prevent deaths from annual floods. Then centre expanded to include every emergency response situation in the city and is the first application of a citywide system that integrates every stage of crisis management from prediction, mitigation, and preparation to immediate response. The centre gathers data across 30 government departments and public agencies, including water, electricity, gas, trash and sanitation, weather and traffic in real-time through fixed sensors, video cameras, GPS devices. Data fusion tools are used to collate this data using algorithms to identify patterns and trends, including most likely incidents. This approach is used to exchange information based on the understanding that overall communication channels are essential to getting the correct data to the right authority to be effective in responding to an emergency. The information-sharing platform enables tapping into various departments and agencies and identifying patterns across diverse datasets to better understand and coordinate resources during a crisis. This centre utilises 560 cameras around the city and another 350 from private and public sector authorities. The incoming feeds of information are aggregated on a single server and displayed across an 80-square meter wall of tiled screens, i.e. a smart map comprised of 120 layers of information that is updated in real-time. More than 400 employees work in shifts through the day every day of the week. The ROC performs various functions to improve the city's efficiency, safety, and effectiveness of relevant government agencies. While the main aim of the centre is emergency monitoring and weather-related responses, the centre also significantly contribute to ensuring the smooth functioning of day-to-day operations like transport.
CCTV Coverage across Sydney rail network	Video surveillance and monitoring	In Sydney, metro stations have extensive CCTV coverage at stations for intrusion detection and monitoring. Video surveillance and monitoring at stations help with crime prevention through environmental design principles. This solutions also incorporates several intrusion prevention and detection systems, including barriers between Sydney Metro and Sydney Trains lines where they occur in the same rail corridor (such as on portions of the T3 Bankstown Line), trackside intruder detection system and trackside CCTV systems. These video surveillance and monitoring systems increase controllers' ability to detect unauthorised access to the Sydney Metro corridor and take appropriate response actions. Sydney Metro trains incorporate full CCTV coverage. Any irregular and unsafe behaviour can be detected in real-time, and a response can be implemented immediately.
Digital customer communication – video travel centres of Deutsche Bahn/DB Vertrieb, Germany	Video surveillance and monitoring	Deutsche Bahn, with its subsidiary DB Vertrieb introduced its first virtual travel centres, which support customers via video conferencing or video sales. There are 90 video travel centres in railway stations or video ticket machines in 10 German federal states, and further expansion is planned. Customers can activate a video chat at the terminals by pushing a button and connecting to an employee at one of the seven video centres in Germany. The employee of the video centres appears on screen and can give personal advice on planning the journey or buying tickets. The employee also has remote access to the ticket machine and can select the right tickets for the customer. Customers benefit from the fact that personal customer services in ticket sales can be ensured even from smaller stations. Customers also benefit from more extended and more consistent business hours. For Deutsche Bahn, it became easier to provide customer support at all times. There were also advantages for employees such as work flexibility.

Oyster card, London, United Kingdom	Electronic and mobile ticketing and payments	This solution was introduced when the number of passengers on the London underground transport showed a dramatic increase. Transport for London started to show interest in getting people through the entrance turnstiles at metro stations faster and decided to invest in Electronic and mobile ticketing and payments for transport options. The multimodal contactless stored value travel smart card Oyster was introduced in 2003 to cover the Greater London region. The card's check-in and check-out technology for fare calculation across the network can hold single and period tickets and other travel permits that need to be added to the card pre-travel, enabling features to include fare capping, concessions, mobile and online top-up facilities, and mobile payments. This card is operated in the Greater London area on various travel modes, including underground metro, buses and light rail. Transport for London had live contactless payment systems on buses since 2012, and by 2013, over 60 million Oyster cards were issued and used to pay for over 85% of all rail and bus travel.
HELMI, Helsinki, Finland	Passenger information systems	The HELMI public transport telematics system, implemented in Helsinki, incorporates real-time passenger information, bus and train priorities at traffic signals and schedule monitoring. This system started with four trams and three bus routes and continuously expanded to add every tram and central bus route. The completed system covers more than 1,800 vehicles. The passenger information relies on the AVL system using GPS-satellite navigation and odometer of the vehicle. The continuous data of each vehicle's exact position on the route is updated into a real-time database and enables displaying the arriving vehicles to the info screens at the stops. These passenger information systems feature information screens off-board and on-board that provides real-time information about the following vehicle approaching the stop/stand. The information includes route number, destination, updating waiting times in real-time.
BRIDJ, Sydney inner West, Australia	Personalised public transport and MaaS	The shuttle service BRIDJ started in Boston, Massachusetts, in 2014. It was implemented in Sydney in 2018. This system evolved to a powerful SaaS designed to support demand-responsive or on-demand transport services. The service platforms include operations portal, passenger and driver applications. The BRIDJ Inner West services provided by Transport for NSW are aimed to serve niche demand areas that is challenging to meet using full-sized buses efficiently. Notably, this route covers the first and last kilometre gaps between existing transport hubs, making it easier to get around the local area. Trials conducted in the Eastern Suburbs of Sydney also aimed to demonstrate the value of this service and whether it can be integrated in the public transport 'service mix' in Sydney to provide passengers with more travel options. The real value of BRIDJ is that it acts as a feeder to and from train stations, especially in peak periods. Payments can be either by a credit card or through OpalPay (Sydney's smartcard system).
Advanced Integrated MaaS – the WienMobil App of Wiener Linien, Austria	Personalised public transport and MaaS	In 2017, the public transport provider Wiener Linien in Australia introduced MaaS. The MaaS concept included different mobility providers such as public transport, bicycle, car-sharing and taxis comprising 18 partners. The concept used the app 'WienMobil' developed by a subsidiary of Wiener Linien, a start-up known as 'upstream'. The app enabled journey planning by accessing real-time information including disruptions and other incidents, reservations and booking of different modes of transport. Additional information, such as the price and environmental friendliness of a selected route is also included. Furthermore, the app enabled users to buy tickets or pay rental providers directly, also taking into account existing public transport tickets (such as annual passes) or memberships with certain car-sharing providers.
Maas by Transdev – Building a MaaS solution, Vienna	Personalised public transport and MaaS	Transdev offers services for urban public transport companies in the area of designing and operating MaaS solutions. Transdev provided integration services (development of user interface, operational platform, management of data, maintenance and updates) and MaaS operation services (general contractor, partner and contract management, marketing, customer services and call centre). In spring 2020, Transdev ran four MaaS initiatives and invested in several external initiatives in various cities around the world. The MaaS concept by Transdev is based on a mobility paradigm that builds on public transport and enables competition, improves safety, efficiency and environmental outcomes and focuses on inclusiveness and accessibility to ensure access for all. Furthermore, it is set up to integrate all modes of local transportation. Significant areas of focus for Transdev to

		achieve the full potential of MaaS are customer service, data collection and analysis, operational efficiency and network design, mobility policy as well as incentives and constraints, contract management, business models and revenue sharing.
KNV Koninklijk Netherlands	Personalised public transport and MaaS	The Royal Dutch Transport Federation (KNV) is the umbrella organisation representing commercial passenger transport operators in the Netherlands. KNV initiated a 'Maas Lab' involving numerous public and private urban transport companies and MaaS providers. The initiative's goal was to organise the new market players and find a basis for working together. The lab is currently involved in seven regional MaaS pilot projects in different regions in the Netherlands, each focusing on a specific objective, such as improving the accessibility of the region, improving the use of urban space or better and less costly transport. All projects are subject to a framework agreement that stipulates, for example, that public transport is at the centre of the approach. Another aim in cooperation with other Benelux countries is to develop a certain degree of standardisation. The standardisation can cover, for example, the aspects of operator information, planning, booking, trip execution, payment and support. Furthermore, an open data system for MaaS is being developed as part of the project.
EZ card, TransitLink, Singapore	Multimodal public transport	In less than two decades, Singapore has become an international benchmark in offering easy and accessible integrated multimodal transport. EZ single fare card was introduced for fare integration in the Singapore transport system on all public transport modes and other applications such as park-and-ride and small retail purchases. This card also enables rebates for intermodal transfers (e.g. rebate of up to SGD$0.25) to be given to passengers who transfer from an MRT station to a bus within 30 minutes. In terms of information integration, TransitLink Guide provides coordinated and comprehensive information on all aspects of travelling on a bus, MRT and LRT, and the information displays facilitate the dissemination of multimodal travel information. Singapore also introduced an 'i-Transport platform' that integrates traffic information from road-based ITS and transit-based measures.
Driver Assistance Systems, Transport for London, United Kingdom	Safety, Public transport management	The 'London's Vision Zero for Buses' is an initiative by Transport for London which aims to reduce the number of fatalities caused by London buses to zero by 2030. This initiative included a comprehensive Bus Safety Programme with technology interventions including driver assistance systems such as intelligent speed adaptation, automatic braking and audible warning systems, as well as measures such as cameras to improve the driver's vision. The programme includes voluntary and mandatory components. For example, with regard to intelligent speed adaption, which has been in operation since 2015, the system cannot be switched off by drivers but automatically reduces speed using a London Digital Speed Limit Map and iBusGPS signal. The 'Mobileye' device was also developed from the project's innovation fund. It includes forward collision warning, pedestrian and cyclist collision warning, lane departure warning as well as a speed limit indicator. The Mobileye has led to a 26% reduction in collisions and a 25% reduction in injuries between 2017 and 2018. Advanced Emergency Braking is planned to be mandatory for London Buses starting in 2024.
Autonomous Shuttles, France	Public transport management	Transdev operates different types of autonomous vehicles and was awarded the world's first commercial contract in 2015 for autonomous shuttle transport services in Rotterdam (Netherlands) with six vehicles operating over a distance of 1.8 km to moving passengers in between a metro station and business centre. Further contracts followed in France and the US, for example, for shuttling passengers across companies' sites, during events or between park-and-ride and tram stations. Increasingly autonomous shuttle services are becoming more complex as they encounter open roads and mixed traffic. Between 2017-2019, the RNAL Project (Rouen Normandy Autonomous Lab) was developed at Le Madrillet in Rouen as the first on-demand transport service using autonomous EVs on an open road in Europe. The vehicles run on three loops that are connected to a terminal of the Metropolis tramway. Passengers call autonomous mini-buses in real-time through an app.

Key freight sector case studies

Project name	Functional area	Description
Demonstration of a fully autonomous garage	Warehousing and contract logistics	In 2018, a pilot project for a fully autonomous bus depot was carried out in Paris. The European Union co-financed this pilot project in the framework of the research programme 'European Bus System of the Future 2 (EBSF 2)' and was the first example of such a depot in Europe. The demonstration project was the culmination of a technological research project conducted by RATP Group (as the operator and project leader), the research lab CEA (algorithms for bus localisation, navigation control) and the bus manufacturer Iveco Bus. For the tests, electric hybrid buses were equipped with sensors and automatic navigation controls for obstacle detection and steering without human intervention. The bus localisation was performed with stereoscopic cameras and inertial measurement units which provided high precision localisation. When the autonomous mode was activated, the vehicle drove into the bus depot and parked itself in the spot assigned by the automatic fleet management system. The goal of the automated bus depots was to shorten bus parking time and optimise the space available in bus depots which were located in dense urban areas.
Truck Platooning, Europe	Freight forwarding, aggregation and customs brokerage	Truck platooning links several trucks in a convoy or platoon using state-of-the-art automated driving support systems with one truck closely following the other. The lead vehicle truck is with a driver while the other trucks following are driverless and are operate autonomously. Platooning trials have been conducted or are underway in Australia, Europe, Japan, Korea, Singapore and the US. Several countries have put forward road maps aimed at multi-brand platooning (with sustained lateral and longitudinal vehicle motion control performed by the system). Such road maps predict that truck platooning at level 2-3 of automation can be attained between 2025 and 2035.
RFID systems, Port of Kaohsiung	Asset and cargo management	Port of Kaohsiung, the largest port in Taiwan, has a geographic advantage in East Asia. More than one million trans-shipment containers are exported and imported to the port annually. The port's operators introduced RFID e-seal technologies to provide more security and reduce smuggling cases. This new RFID system can save with inspection time and reduce costs.
Hong Kong Airport Shopping	Technology-based services for e-commerce support	The Airport Authority of Hong Kong worked with a technology supplier to create an online shopping platform – HKairportShop.com. With more than 70 million passengers moving through the airport every year, a decision was made to develop this online shopping platform to make it easier for passengers to find what they want. The project ran from March 2017 until February 2021 and included integration of a large number of applications, technologies and services including online shopping (web site and mobile app), retailers' inventory management system, payment gateway, omnichannel order fulfilment system, e-coupon system, CRM, data analytics and marketing automation applications, multi-channel social platforms integration, 24/7 system and application support and 24/7 customer service. The online system was shown to have a substantial improvement on passenger shopping experience.

Key rail sector case studies

Project name	Functional area	Description
METRONET: High Capacity Signalling in Perth	Information and communication technology services	The Western Australian Government project will implement an Automatic Train Control system using modern, radio-based, high-capacity communications-based train control technology on all three line-groups of the Perth metropolitan railway network. The project includes the construction of a purpose-built Rail Operations Centre, a back-up Signalling Equipment Room and an upgrade of the existing Alternate Train Control facility. Economic benefits of the project include shorter wait times, reduced train crowding, and travel-time savings for public transport users. Other benefits include reduced vehicle emissions and operating costs, health benefits, and road-safety benefits. The stated BCR was reported at 2.6, with a net present value of A$688 million (7% real discount rate).
Fully and semi-automated metros Communication-Based Train Control (CBTC) at Budapest Transport Ltd.(BKV)	Information and communication technology services	Around 60% of public transport in Budapest city is covered by metros. The system currently has four metro lines. Line 2, which first opened in 1970, became partly automated (Grade of Automation 3) in 2013 (a supervisor monitors the train in the cab). Line 4, introduced in 2014, is a new fully automated line (Grade of Automation 4) and runs unattended. Line 4 has added levels of sophistication including automated driving and stopping, opening and closing of doors and stopping immediately at a safe location in the event of an incident. The core of the system is the Communication Based Train Control system 'Trainguard' from Siemens. The system uses a 'moving block' control system, where the protected section for each train is a 'block' that provides continuous communication of the train's exact position, allowing shortening intervals between trains. The Siemens signalling allows for up to 30 trains/h. Services run at 2 to 3 minutes headways in peak times and at 5 to 10 minutes in off-peak hours.
Digitalisation of maintenance at Metro de Madrid and TMB Transports Metropolitans de Barcelona, Spain	Asset condition monitoring	At Metro de Madrid, projects of digitalised maintenance focus on the use of train and equipment information to improve maintenance plans and predict failures and breakdowns. Furthermore, the state of installations and trains is constantly monitored, and telematics applications are used to carry out maintenance activities. Metro de Madrid also started to modernise/automate warehouses and parts management. The company provides customers with opportunities to report incidents by taking and sending photos to the maintenance department. As the public transport provider, TMB Barcelona introduced a predictive maintenance and automated diagnostic system which consists of a broad range of measures such as remote image taking of devices to verify their position; threshold-related alarms, detection of failure patterns, and trend analysis to provide quality parameters for condition and predictive maintenance. Further elements include sensor-based interventions, constant measuring tunnel and track temperature, sensor-based monitoring of rail forces and stressed parts (e.g. train doors), and digitalising job orders at bus rolling stock workshops.

Key aviation sector case studies

Project name	Functional area	Description
Jeju International Airport Checkpoint Screening	Safety and security	Smiths Detection worked closely with the airport to install HI-SCAN 6040 CTiX to harness the latest Computed Tomography (CT) X-ray technology for checkpoint screening. This provided the airport operator with better opportunities for enhancing customer experience even as the number of visitors continued to grow. Checkpoint operators can now clear 400 to 500 trays per hour—a 50% increase from using conventional 2D X-ray systems. This is reported to have led to a 50% increase in throughput and allowing passengers to leave electronics/liquid in bags during scans. It also provided improved capabilities for explosive tracing and identification in less than 8 seconds.
Shenzhen Airport Intelligent Aircraft Stand Allocation	Airport operations	Shenzhen International Airport set up an Intelligent Aircraft Stand Allocation System at the end of 2019.The purpose of this system is to implement intelligent allocation and scheduling of aircraft parking space resources by using AI solutions and optimising the core operating indicators of the airport, such as increasing the airbridge turnover and reducing the aircraft taxiing conflict probability, thereby improving the overall operation efficiency and passenger experience. This system helped Shenzhen Airport to reduce the aircraft ground taxiing collision probability, and visualizing the allocation outputs or results to make it easier for checking and verification. It also increased the airbridge usage and improved airport resource utilisation and reduced related operating costs. The airbridge usage increased by nearly 5% resulting in at least 30 more aircrafts and 5,000 more passengers using airbridges for boarding or disembarking each day.
London Heathrow Airport Autonomous Robot	Airport operations	British Airways is trialling autonomous robots to guide passengers around Terminal 5. They have also trailed self-driving luggage vehicles and installed automated bag drop machines and self-boarding technology across the airport. They have undertaken extensive staff training programs to enable staff to utilise a suite of specialised apps to help respond quickly to customer queries and resolve any problems rapidly.
Blockchain Digital Wallet at Singapore Airport	Airport operations	The airport is integrating technologies including sensors, data analytics, and AI to enhance customer experience and improve productivity. The airport developed a blockchain-based digital wallet that enables passengers to use frequent flyer rewards at airport retailers. The airport technology extension is part of a project named 'Jewel Changi', costing SGD 1.7 billion. The blockchain digital wallet was launched in 2018. The 'Jewel Changi' airport extension opened in 2019.
Self-service Kiosks At Hamad Airport, Doha	Capacity management	The airport launched next-generation self-service check-in kiosks and self-service bag drops with biometric technology capability. Additionally, a mobile Automated Visa Document Check has been introduced which enables ground service operators to check passenger visa documentation before they board. The self-service kiosks are faster than traditional methods, allowing passengers to process one bag in less than 50 seconds. It is estimated that the technology will speed up the processing by 40%. The self-service kiosks and bag drop facilities have been available to passengers since 15th October 2018.
Dubai Airport smart Tunnel	Capacity management, security and safety	Dubai Airport's Smart Tunnel uses facial recognition and AI to allow passengers to go through passport control procedures in just 15 seconds without human intervention. The project had a high investment cost but led to substantial improvements in operation and cost savings through passenger efficiency clearing customs and reduction in human involvement in the process. It took four years to develop the Smart Tunnel which was launched in October 2018.

Key maritime sector case studies

Project name	Functional area	Description
WERA HF Radar, Germany	Safety and security	The WERA (WavE Radar) surveillance network is a shore-based remote sensing system developed at the German University of Hamburg to monitor ocean surface currents, waves, and wind direction. This oceanography radar picks up back-scattered signals from rough ocean surfaces from over 200 km. It allows a wide range of working frequencies, high-resolution spatial monitoring over a range of 60km and high temporal resolution of 10 minutes, and antenna configurations to operate as low power oceanographic radar providing simultaneous wide-area measurements of surface currents, ocean waves, wind parameters, and detecting ships.
Port of Rotterdam, Netherlands	Port operations	In 1993, the East Container Delta Terminal in Maasvlakte Rotterdam was the world's first fully automated container terminal. Later, the Port of Rotterdam expanded the scale of automation. IoT technology enabled the creation of a digital twin – an exact digital replica of port operations to visualise every resource at the port of Rotterdam, including real-time tracking of ship movements, accurate monitoring of infrastructure, weather, geographical and water depth data. IoT sensors, Augmented Intelligence and smart weather data is used to measure the berth availability and other vital statistics. For example, using accurate water (hydro) and weather (meteo) data enable the possibility to predict the arrival time for the port of Rotterdam by analysing environmental conditions.
Port of Rotterdam, Hamburg	Port operations	In 2002, the Container Terminal Altenwerder in the Port of Hamburg implemented the world's second fully automated container terminal. Hamburg also has another semi-automated terminal, namely, the Container Terminal Burchardkai.
Paperless Trade e-SPS, Netherlands and China	Administrative procedures	A five-year project was launched by the Netherlands and China in 2010, aiming to launch a pilot project on implementation of electronic SPS (Sanitary and PhytoSanitary) certification. This paperless trade project used standard XML messaging developed for electronic SPS certificates. Paper certificates are in most cases produced on security paper and signed and stamped to provide proof of integrity and authentication. As a result, each electronic message containing the SPS certificate was accompanied by an electronic signature using the XMLDSig standard. The electronic signature management was based on the FIPS 140-2 (National Institute of Standards and Technology of the USA) standard terms of technology and procedures. The shift also required legal frameworks that recognised the electronic signature.
YARA Autonomous Ships, Norway	Ocean and short-sea shipping	This is a fully electric autonomous container ship carrying fertiliser products from YARA's production site in Hrøya to the nearby ports in Brevik and Larvik in Norway's southern Telemark region. This initiative is improving how supply chain transport is practised in Norway and if successful, this model may be replicated for similar cases around the world. Phase 1 of the project includes a remotely controlled and human-crewed vessel. The subsequent stages will include a shift from remote control unmanned to autonomous unmanned. The final stages will include a shift from decision-support to decision-making, although shore-based supervision is expected to remain until further automation is achieved.
EU-financed MONALISA 2.0 project, Testbeds Port of Gothenburg, Sweden and Port of Valencia, Spain	Maritime traffic management	This project was delivered in 2015 with a vision of how shipping can be turned into a more efficient, safe and environmentally friendly transport mode through Sea Traffic Management (STM). This resulted in Port Optimizer, which is a cloud-based software solution integrating data from across the port ecosystem with a unique identifier for each voyage. It also included continuous real-time based information sharing for just-in-time operations, improved navigational safety and enhanced sea traffic efficiency. The project resulted in improvements of how shore and vessel can interact to improve safety in dense traffic areas, and demonstrated how collaborative decision making between ports can improve operations for all stakeholders.

Key active transport sector case studies

Project name	Functional area	Description
Bike Light Technology	Safety, Travel experience and fleet management	The Transport Accident Commission in Australia is collaborating with Deakin University, See.Sense and the iMOVE CRC to run an Australia-first trial using See.Sense's smart bike light technology. The technology will allow cyclists who participate in the trial to share information which will be used to understand how they ride and what issues impact their safety. If the trial is successful, the insights could be used to help inform future policy planning and infrastructure improvements for cyclists. More than 1,000 Victorian cyclists, of all abilities, have been specially selected to participate in the trial over a 12-month duration.
Sensor-powered advanced driver-assistance systems	Safety, Travel experience and fleet management	Ford-owned scooter (SPIN) company teamed up with Drover AI to add new technology to its e-scooters. Their aim was to embed cameras, sensor arrays, and onboard computers to all of their e-scooters to curb improper parking and riding behaviour by customers. This will assist riders in making safe riding decisions and reduce risks of injuries to other road users due to cluttering of sidewalks.
Accurate e-scooter Parking	Parking management and travel experience and fleet management	In this initiative, a European e-scooter operator TIER partnered with mapping company Fantasmo to create an e-scooter parking system to bring order to city streets and protect vulnerable road users. Camera Positioning System, a new positioning technology that is substantially more accurate than GPS, is used to validate e-scooter parking within 20cm or less using a standard phone's camera. The key advantage is that the system does not require any physical infrastructure and if successful will resolve a major concern for transport authorities. The initiative is initially being rolled out in York and Paris, and will later be introduced in other locations across TIER's network of 85+ cities throughout Europe and the Middle East in 2021.
Computer Vision Technology	Fleet Management	Swedish e-scooter company Voi worked with Irish start-up Luna who is offering real-time lane segmentation and pedestrian detection for scooters with an accuracy similar to systems that are available in high-end cars. Voi previously launched a large scale pilot of computer vision systems on e-scooters that deploys an AI solution to detect when the scooter leaves the road and rides on a pavement, or when the vehicle is parked incorrectly. The technology solution also provided tools to identify problem areas for micro-mobility riders by conveying real-time data about the quality of riding infrastructure and how the vehicles are being used. The computer vision algorithms were trained extensively using hours of video footage from Northampton, Stockholm.

Key common sector functional areas case studies

Project name	Functional area	Description
Digitalisation of Maintenance at Transdev, France	Infrastructure services and predictive asset maintenance	Transdev, the French-based international private-public transport operator operates a digitalised maintenance system aimed at improving the safety and availability of the fleet. Digitisation solutions enabled an anticipatory, digitalised, connected maintenance regime that is expected to provide a clear added value regarding service quality, operational efficiency, and costs. According to the company, digitalisation and the move towards connected workshops had clear advantages at several dimensions. The overall advantage related to the reduction of maintenance costs, rationalisation of processes, communication processes between different entities, and optimisation of vehicle fleets. Transdev also regards digitalised maintenance as having positive impacts on customers (increase in security) and the environment (paperless processes).
Generic Maintenance Platform at GVB, Paris France	Infrastructure services and predictive asset maintenance	Many transport organisations rely on vehicle fleets that use very different technologies. From the perspective of maintenance and the transition towards predictive maintenance, this is a challenge. GVB in Amsterdam, a public transport provider, developed a generic platform that combined different systems of vehicles and suppliers. The data gathered provided an opportunity to establish a platform that combined baseline data and real-time information from all vehicles which is used to predict maintenance requirements to ensure breakdowns are avoided.