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Smart Mobility: Unlocking the Value of the Internet of Things

This input paper was prepared by Hussein Dia, Rusul Abduljabbar and Sohani Liyanage

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Smart Mobility: Unlocking the Value of the Internet of Things

Hussein Dia, Rusul Abduljabbar, Sohani Liyanage

Department of Civil and Construction Engineering
Swinburne University of Technology
Melbourne Australia

Email for correspondence: HDia@swin.edu.au

Abstract

The Internet of Things (IoT) – or digitising the physical world – has experienced rapid growth in recent years, and has benefited from the fast pace of innovations and scientific advances in a number of areas including sensor technologies, algorithms and data analytics. IoT 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 will 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 to measure performance of infrastructure and assets and transform operations. We are already witnessing how converging the physical transport assets and the digital world is opening new possibilities to improve the travel experience for city dwellers. Moving forward into the future, the IoT impacts will be more profound with the advent of connected and automated vehicles, on-demand autonomous shared mobility, Artificial Intelligence (AI) and data analytics. The coming together of innovations in these fields will provide travellers with high-quality urban mobility services. This paper describes how IoT-driven digital innovations will allow for real-time analysis of mobility patterns, and enhance the quality of trips for travellers. The paper also identifies the challenges and barriers for widespread deployed, and the policy principles which will be crucial to the success of IoT-driven smart transport solutions.

1. Introduction

The planning and operation of transport systems that provide efficient movement of people and goods remains one of the major challenges facing cities around the world. Despite decades of investment in transport infrastructure, today's mobility is still hindered by high levels of congestion, long travel distances, unreliable travel times, and declining levels of road safety. Moreover, these issues will become more pressing in the future as our world becomes more urbanised.

The challenges facing mobility in cities are compounded by the interaction of a number of issues, which include traffic congestion, rapid urbanisation, road crashes and injuries, emissions, ageing infrastructure, constrained budgets, social equity, system resilience, energy provision, climate change, and health. Key solutions and priorities that have been prescribed include travel demand management, land use-transport integration, optimisation of transport operations and reducing reliance on building more roads, intelligent transport systems, digital innovations and disruptive technologies, and public and active transport solutions.

In recent years, however, the fast pace of breakthroughs in new technologies and scientific advances has been relentless, and is expected to continue to unfold on many fronts. Often, it becomes difficult and challenging to identify which technologies may unleash disruptive changes and impact the growth and performance of the transport sector. One technology that has been identified as “disruptive” and will have a massive impact on how people travel, live and work is the Internet of Things. A “disruptive technology” is usually identified based on four characteristics: (1) the technology is rapidly advancing or experiencing breakthroughs; (2) the potential scope of impact is broad; (3) Significant economic value could be affected; and (4) Economic impact is potentially disruptive.[1]

This article explores how the emerging forces of IoT combined with other digital innovations and disruptions will have sweeping impacts on the management of infrastructure. The article identifies emerging trends and is aimed at guiding asset operators, leaders and policy makers to fully appreciate and consider the reach of these disruptive technologies, and how they might impact future investment in transport infrastructure.

3. The opportunities

The Internet of Things and the embedding of sensors and actuators in machines and other physical objects to bring them into the connected world, is spreading rapidly. By converging the physical and digital realms, the IoT vastly expands the reach of information technologies.

Cities, in particular, have become the focus of a great deal of innovation and experimentation with IoT technology, through so-called smart city initiatives. Specifically, cities can benefit from IoT in four areas: transport, public safety and health, resource management, and service delivery. From monitoring the flow of water through utility pipes to measuring vibrations on bridges or tracking vehicle fleets, the Internet of Things allows businesses and public-sector organisations to manage assets and optimise performance.

In transport, our urban areas are effectively comprised of complex networks that are interconnected, providing an opportunity for better infrastructure management. Transport is therefore seen as one of the strongest application areas and would include IoT-based systems to improve personal mobility. For example, adjusting commuting schedules based on actual tracking data of public transit systems to reduce buffer times (extra time between when the traveller arrives at a bus stop or transit station and when the bus or train actually arrives, which in some cities has been estimated at a staggering 70% of the daily commute time.[1] It is estimated that reducing this buffer time could provide time savings equivalent to more than $60 billion per year.

Moving forward, sensors in urban environments will communicate with each other to enhance infrastructure capability and resilience. In the process, they will capture volumes of data. Through artificial intelligence and predictive analytics tools, they will result in smart infrastructure systems can help city managers to monitor the performance of vital assets, identify key areas where city services are lagging, and inform decision makers on how to manage city growth and make our cities more liveable.

The recent advances in technology-driven urban innovations have manifested themselves in what has been referred to as “Smart Infrastructure.” This framework includes applications of advanced technologies, data analytics, and AI predictive algorithms to improve the performance of infrastructure and asset management in the built environment, as shown in **Figure 1.**

With this framework, future cities will include control systems that use sensors to detect and respond to infrastructure deterioration and operational faults. When their use is widespread, they will improve vital city services by monitoring the health of critical infrastructure and

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[1] Gao, P., Kaas, H.-W., Mohr, D. & Wee, D. 2016. Automotive revolution–perspective towards 2030: how the convergence of disruptive technology-driven trends could transform the auto industry. *Advanced industries, mckinsey & company*.

identifying potential breakdowns before they occur.[2] **Figure 1** shows technology used only as an enabler to achieve a community's desired objectives which may include objectives such as sustainability, citizen well-being and economic viability.

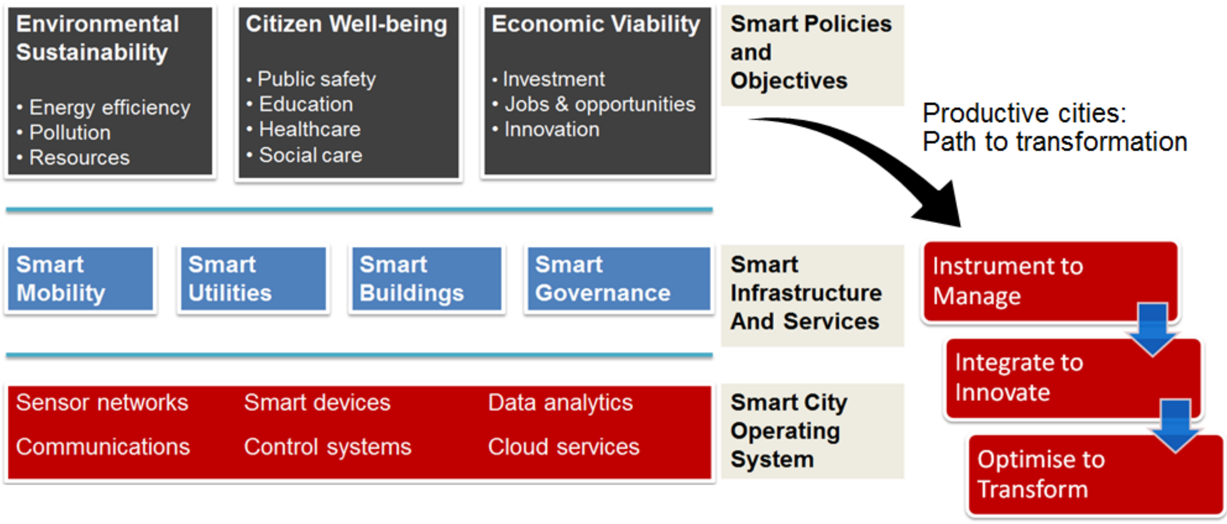

Figure 1: "Smart infrastructure" framework underpinned by digital innovations

The key consideration in this framework is a recognition of the role of digital platforms, which include IoT, in charting a path towards sustainable and productive cities. To enable this, priority is given to widespread instrumentation to allow for measuring and managing assets; fusing and integrating the data from different sources; and optimising performance in order to transform operations.

3.1 IoT enabled smart mobility

Smart mobility encompasses the use of technology and advanced algorithms to provide travellers with seamless and flexible trips across all modes of transport. This includes private vehicles, public transport buses, trains and trams, ride-sharing and car-sharing services and on-demand micro-mobility such as rental e-bikes and e-scooters. While most cities today have some forms of these modes of transport, the key challenge is to integrate them into a system that provides users with a seamless travel experience. This is also giving way to new business models and innovations such as Mobility-as-a-Service (MaaS).

To enable this type of connected and integrated travel, a number of technology and digital innovation elements must be converged including the IoT-instrumented smart infrastructure, and the data analytics tools and algorithms that fuse the information and provide actions. Once converged, they offer opportunities for disruptive mobility solutions.

In practice, this would lead to 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.[3] These systems will also enhance personal mobility through providing travellers with up-to-date and

[2] Batty, M. 2013. Big data, smart cities and city planning. *Dialogues in human geography,* 3**,** 274-279.
[3] Winston, C. & Mannering, F. 2014. Implementing technology to improve public highway performance: a leapfrog technology from the private sector is going to be necessary. *Economics of transportation,* 3**,** 158-165.

real-time information about public transport schedules, connections, available capacities on arriving trains, trams and buses, and expected arrival times.[4] Near railroad level crossings, a range of train-to-infrastructure and train-to-vehicle technologies will improve safety and provide warnings to avoid collisions.[5]

3.2 Application Areas in Transport

In this section, we describe the IoT application areas and opportunities in four categories: Traffic control and management, connected and automated vehicles, in-vehicle systems and managing/ monitoring transport infrastructure.

3.2.1 Traffic control and management

Cloud platforms that can access vehicular data enables the exchange of transport-related information[6] that can aid in traffic signal control, real time traffic monitoring, real time incident detection, future traffic prediction and route optimisation which are useful for traffic control and management.[7]

For example, an integrated system of sensors and vehicles communication to control traffic at signalised intersections has been proposed, to improve mobility by reducing number of stops, minimise travel delays and increase road safety.[8] Simulation experiments were conducted and calibrated to test the system for two hours during different control scenarios for red, yellow and green time in Redwood Arterial Road, Salt Lake City, United States. The integrated model decides which action to take during different traffic control paradigms and give feedback control to the drivers and the signal controller through VISSIM-COM interface. The results showed the efficiency of the model in reducing intersection crash rates and improving mobility needs.

In another example, a scalable urban traffic control system named SURTRAC is developed for better intersection management in United States.[9] The system collects sensor data and applies Artificial Intelligence (AI) for real-time traffic flow monitoring of the intersection. The system is able to reduce travel time by 26%, and waiting time by 41%.

Rathore et al developed a system to monitor real time vehicle behaviour captured from the network cameras, and from video cameras attached to the front and rear of vehicles.[10] The results showed that the system was able to detect real-time unusual behaviour such as, unauthorised U-turn, access speeding limits and other dangerous driving behaviour.

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[4] Neumann, C. 2015. Big data versus big congestion: using information to improve transport. *Mckinsey & company*.
[5] Group, R. L. C. 2010. National railway level crossing safety strategy, australian transport council.
[6] Liyanage, S., Dia, H., Abduljabbar, R. & Bagloee, S. A. 2019. Flexible mobility on-demand: an environmental scan. *Sustainability,* 11**,** 1262.
[7] Abduljabbar, R., Dia, H., Liyanage, S. & Bagloee, S. A. 2019. Applications of artificial intelligence in transport: an overview. *Sustainability,* 11**,** 189.
[8] Yang, X., Chang, G.-l., Zhang, Z. & Li, P. 2019. Smart signal control system for accident prevention and arterial speed harmonization under connected vehicle environment. Transportation research record, 2673, 61-71.
[9] Xie, X.-F., Smith, S. F. & Barlow, G. J. 2015. Smart and scalable urban signal networks: methods and systems for adaptive traffic signal control. Google patents.
[10] Rathore, M. M., Son, H., Ahmad, A. & Paul, A. 2018. Real-time video processing for traffic control in smart city using hadoop ecosystem with gpus. *Soft computing,* 22**,** 1533-1544.

According to Kumar et al more than 80% of vehicles sold in 2020 are expected to have devices integrated with other systems and connected via smart phone.[11] The authors develop a system using Internet of Vehicle data (IoV) to find the optimal routing for vehicles, minimise congestion and accidents. IoV is intended to provide services to vehicles through Internet Cloud for better communication with the surrounding vehicles and detection of potential hazards.[12] The proposed system was able to minimise travel time and average waiting time by finding best optimum routes using Ant Colony Algorithm and Fuzzy logic functions to measure the flow intensity of selected road.

3.2.2 Connected and automated vehicles

Connected Vehicles (CV) represent a rich environment for development and deployment of IoT and cloud-based services. Vehicular Communication (V2X) plays an important role for the next generation of intelligent transport systems (ITS) and Network communication Development. This includes vehicle-to-Vehicle (V2V) and vehicle-to Infrastructure (V2I) messaging. Datta et el developed an integrated IoT framework for connected vehicles with a mechanism to facilitate integration of data collected from vehicles, and overcome data fusion problems by combining vehicle data with environmental data on a single computing platform.[13] González-Plaza et al developed a tool to improve V2X communication that emulates the communication links between vehicles and asses any problems occurring due to lack of wireless coverage.[14] These studies showed the benefits of V2X include: increase pedestrian safety[15] and reduced vehicle crashes through advanced messages warning systems, [16] improve network capacity, stabilised traffic flow, and reduced emissions by using Cooperative Adaptive cruise control (CACC) systems[17]

Automated Vehicles (AV) are also being developed with IoT technologies, and are expected to have wide impacts.[18][19] AVs are expected to be a new form of public transport especially useful for the first and last kilometre of travel, and if not managed well may result in different social structures and adverse urban forms. If well planned and implemented, they will help in car sharing and ride sharing with new business models for solutions to existing barriers,

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[11] Kumar, P. M., Devi, U., Manogaran, G., Sundarasekar, R., Chilamkurti, N. & Varatharajan, R. 2018. Ant colony optimization algorithm with internet of vehicles for intelligent traffic control system. *Computer networks,* 144**,** 154-162.
[12] Gerla, M., Lee, E.-K., Pau, G. & Lee, U. Internet of vehicles: from intelligent grid to autonomous cars and vehicular clouds. 2014 ieee world forum on internet of things (wf-iot), 2014. Ieee, 241-246.
[13] Datta, S. K., Da Costa, R. P. F., Härri, J. & Bonnet, C. Integrating connected vehicles in internet of things ecosystems: challenges and solutions. 2016 ieee 17th international symposium on a world of wireless, mobile and multimedia networks (wowmom), 2016. Ieee, 1-6.
[14] González-Plaza, A., Briso-Rodríguez, C. & Gutiérrez-Cantarero, r. Network emulator for v2x communication systems. 2019 13th european conference on antennas and propagation (eucap), 2019. IEEE, 1-5.
[15] Zeng, Z., Ash, J., Pu, Z., Zhuang, Y. & Wang, Y. 2018. A framework of a v2x communication system for enhancing vehicle and pedestrian safety at un-signalized intersections.
[16] Khan, M. L., Aubet, F.-X., Pahl, M.-O. & Härri, J. 2019. Deep learning-aided application scheduler for vehicular safety communication. *Arxiv preprint arxiv:1901.08872*.
[17] Milanés, V., Shladover, S. E., Spring, J., Nowakowski, C., Kawazoe, H. & Nakamura, M. 2013. Cooperative adaptive cruise control in real traffic situations. *Ieee transactions on intelligent transportation systems,* 15**,** 296-305.
[18] Fagnant, D. J. & Kockelman, K. 2015. Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. *Transportation research part a: policy and practice,* 77**,** 167-181.
[19] Javanshour, F., Dia, H. & Duncan, G. 2019. Exploring the performance of autonomous mobility on-demand systems under demand uncertainty. *Transportmetrica a: transport science,* 15**,** 698-721.

such as limited accessibility and reliability.[20] The hardware architecture in AVs is comprised of actuators, sensors and a computer system while the software component comprises the AI self-driving system, navigation modules, localisation algorithms and perception systems to detect moving objects.[21]

3.2.3 In-vehicle systems

IoT is expected to play an important role in road safety and minimising road crashes and injuries. This can be achieved through on-board vehicle systems, which use information from connected sensors in the vehicle to monitor vehicle conditions, environment and the driver.[22] Smart IoT techniques can be used to monitor speed, detect real time incidents and provide real time warning to inform the drivers and road agencies of any hazardous situations on the road. For example, a Driver Smart Advisory System (DSAS) has been tested.[23] It provided warning messages about hazardous situations on the road resulting in improved driver behaviour as it encouraged drivers to maintain headway distances and reducing speeds in work zones to prevent crashes. The system was also found to reduce emissions. [24] The efficiency of in-vehicle smart advisory systems have also been tested and demonstrated its ability to reduce delays and emissions.[25]

3.2.4 Predictive maintenance and management of transport infrastructure

Poor maintenance of infrastructure can be costly and may result in damage to vehicles and risk drivers' safety.[26] IoT can transform the way our transport infrastructure is maintained through sensors and data analytics. Poor road conditions and aging infrastructure can also cause major congestion and road crashes. Bridge monitoring, for example, can reduce the need for costly maintenances and ensures the safety of the bridge for travellers. For example, sensors can be embedded in steel girders to assess the performance of the bridge, and providing data on possible damage within hinges. This has proved to be effective when tested on numerous bridges.[27] Road maintenance is important for ensuring safety on our roads. The presence of potholes effect road safety.[28] A system that assesses road conditions in real time based on AI neural network support vector machine models in New

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[20] Kornhauser, A., Chang, A, Clark, C, Gao, J, Korac, D, Lebowitz, B & Swoboda, A 2013. Uncongested mobility for all: new jersey's area-wide ataxi system. *Operations research and financial engineering.*

[21] Chong, Z., Qin, B., Bandyopadhyay, T., Wongpiromsarn, T., Rebsamen, B., Dai, P., Rankin, E. & Ang, M. H. 2013. Autonomy for mobility on demand. *Intelligent autonomous systems 12.* Springer.

[22] Albornoz, J., Fujitsu Ltd 2015. Vehicular safety system. U.s. patent application 14/674,631.

[23] Li, Q., Qiao, F. & Yu, L. 2016. Vehicle emission implications of drivers' smart advisory system for traffic operations in work zones. *Journal of the air & waste management association,* 66**,** 446-455.

[24] Wan, N., Vahidi, A. & Luckow, A. 2016. Optimal speed advisory for connected vehicles in arterial roads and the impact on mixed traffic. *Transportation research part c: emerging technologies,* 69**,** 548-563.

[25] Lee, J., Gutesa, S., Dimitrijevic, B., Zhang, Y., Spasovic, L. & Singh, J. 2017. Deployment and field evaluation of in-vehicle traffic signal advisory system (itsas). *Information,* 8**,** 72.

[26] Mednis, A., Strazdins, G., Zviedris, R., Kanonirs, G. & Selavo, I. Real time pothole detection using android smartphones with accelerometers. 2011 international conference on distributed computing in sensor systems and workshops (dcoss), 2011. IEEE, 1-6.

[27] Kurata, M., Kim, J., Lynch, J., Van der Linden, G., Sedarat, H., Thometz, E., Hipley, P. & Sheng, I.-H. 2012. Internet-enabled wireless structural monitoring systems: development and permanent deployment at the new carquinez suspension bridge. *Journal of structural engineering,* 139**,** 1688-1702.

[28] Eriksson, J., Girod, I., Hull, B., Newton, R., Madden, S. & Balakrishnan, H. The pothole patrol: using a mobile sensor network for road surface monitoring. Proceedings of the 6th international conference on mobile systems, applications, and services, 2008. ACM, 29-39.

South Wales, Australia has been proposed.[29] The proposed system successfully detected 97.5% of road damage on the road. Deep learning techniques were used to improve accuracy of data collected from sensors for the automatic detection of different kinds of road surface conditions, with the results showing a high detection accuracy.[30] Some of the more recent advances in this space allow for creating digital simulation models by integrating IoT, AI, data analytics and machine learning. The models provide updates when a change is detected in the cyber-physical system. This helps to optimise real-time monitoring and provide updates from various sources at the same time.[31]

3.2.5 Real-time integrated multi-modal travel information

Provision of quality public transport services is one of the most effective ways to provide mobility services and meet the travel demands of increasingly connected populations. Access to reliable real-time integrated travel information is critical for successful public transport operations.[32] In many cities, access to real-time information is available as a result of big advancements in automated vehicle location systems, Internet of Things (IoT), and mobile computing technologies. This enables the concept of real-time integrated multi-modal travel information, which focuses on providing information on mode all choices to users on a single enquiry in real-time. For travellers, usually planning their trips is a complex decision due to lack of reliable information, difficulties in identifying and assessing the feasible itinerary.[33] Therefore, real-time information about the location of the vehicle, waiting time, predicted arrival times benefit the user who can compare between available modes and decide which mode to use to reach their desired destination.[34] Research in this field e.g. shows how online passenger information systems for interurban multimodal trips can support trip-planning decisions.[35] A multi-modal travel information system named PATH2GO w along a corridor in San Francisco Bay was designed to provide users with the information in one platform, and explored how travellers are encouraged by accessing to multimodal travel information to consider transit as a viable travel option.[36] The research found how availability of real-time integrated multi-modal travel information benefits passengers by decreasing waiting time, overall travel time. It also showed these systems, which are IoT-enabled, improved ridership, increased passenger satisfaction, and increased personal security.[37]

3.2.6 On-demand public transport

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[29] Anaissi, A., Khoa, N. L. D., Rakotoarivelo, T., Alamdari, M. M. & Wang, Y. 2019. Smart pothole detection system using vehicle-mounted sensors and machine learning. *Journal of civil structural health monitoring,* 9**,** 91-102.

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[31] Constante, t. A. D. S. L. 2018. Contribution for a simulation framework for designing and evaluating manufacturing systems.

[32] Grotenhuis, W. W., Wiegmans, B. W. & Rietveld, P. 2007. The desired quality of integrated multimodal travel information in public transport: customer needs for time and effort savings. *Transport policy,* 14**,** 27-38.

[33] Zografos, K., Spitadakis, V. & Androutsopoulos, K. 2008. Integrated passenger information system for multimodal trip planning. *Transportation research record,* 2072**,** 20-29.

[34] Kenyon, S. & Lyons, G. 2003. The value of integrated multimodal traveller information and its potential contribution to modal change. *Transportation research part f: traffic psychology and behaviour,* 6**,** 1-21.

[35] Zografos, K., Spitadakis, V. & Androutsopoulos, K. 2008. Integrated passenger information system for multimodal trip planning. *Transportation research record,* 2072**,** 20-29.

[36] Zhang, L., Li, J.Q., Zhou, K., Gupta, S. D., Li, M., Zhang, W. B., Miller, M. A. & Misener, J. A. 2011. Traveler information tool with integrated real-time transit information and multimodal trip planning: design and implementation. *Transportation research record,* 2215**,** 1-10.

[37] Brakewood, C. & Watkins, K. 2019. A literature review of the passenger benefits of real-time transit information. *Transport reviews,* 39**,** 327-356.

Conventional public transport systems operate according to a timetable on fixed routes, which can be cost-effective to service operator in urban areas during peak times due to maximum vehicle utilisation. However, services are usually reduced during off-peak periods and in low-dense areas due to lower demands leading to poor performance and reduced traveller satisfaction.[38] Therefore, novel public transport business models, such as on-demand public transport, are increasingly becoming attractive as a new form of transport.[39] [40][41]The operation of on-demand services has evolved over the years and had its origins in the provision of door-to-door services for special transport users such as elderly and disabled. Today, on-demand mobility services include taxi services, ride-hailing (e.g. Uber, DiDi, and Lyft), car-sharing (e.g. GoGet) and in more recent times on-demand public transport buses. Their success is being underpinned by app-based systems and are likely to improve the first and last-mile public transport in urban areas.[42] These services are designed in a user-centric approach to provide the users with a more convenient, efficient, reliable and safer service.[43][44][45][46]

The emerging uses of IoT will provide access to unprecedented levels of data with real-time analysis of traffic and weather conditions.[47] Using real-time data to establish origin-destination demand, the on-demand mini-bus service (based on BRIDJ technologies) now operates in Sydney.[48] Key challenges in this space include fleet size optimisation, passenger demand prediction, and providing reliable and timely services to users. Overcoming these challenges will provide opportunities to enhance performance from the commercial, operational and user acceptance perspectives. It is expected that IoT will increase access to real-time data which will help with optimising future on-demand services.

6.0 Barriers to deployment

To improve adoption rates and speed up deployment, three main areas of concern that need to be addressed are reported next.

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[38] Liyanage, S., Dia, H., Abduljabbar, R. & Bagloee, S. A. 2019. Flexible mobility on-demand: an environmental scan. *Sustainability,* 11**,** 1262.
[39] Pavone, M., Smith, S. L., Frazzoli, E. & Rus, D. 2012. Robotic load balancing for mobility-on-demand systems. *International journal of robotics research,* 31**,** 839-854.
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[45] Ma, J., Yang, Y., Guan, W., Wang, F., Liu, T., Tu, W. & Song, C. 2017. Large-scale demand driven design of a customized bus network: a methodological framework and beijing case study. *Journal of advanced transportation,* 2017.
[46] Rosin,J. 2018. *Optibus uses artificial intelligence to improve mass transit's on-time performance and prevent delays* [online]. Available: https://finance.yahoo.com/news/optibus-uses-artificial-intelligence-improve-110000554.html?guccounter=1 [accessed 27 october 2018].
[47] Burrows, A. & Bradburn, J. 2015. *Journeys of the future*.
[48] Transport., n. T. O. D. P. 2018. Available: https://transportnsw.info/travel-info/ways-to-get-around/on-demand-public-transport [accessed 17 december 2018].

6.1 Regulations

As with other rapid advancements in technology, regulators are often challenged to keep up with the pace of innovations and how to provide the market with guidance on privacy, security and other issues that might affect their widespread deployment.[49] This renders traditional regulations and legal policies obsolete and insufficient to deal with the modern realities of digital innovations and the interconnectedness of IoT devices.[50][51] There is also a need for consistent regulations across all states and jurisdictions including designation of a consistent environment in which these technologies can operate. There is also a need for a regulatory framework that recognises market uncertainty in the face of fast technology developments, and instead focuses on agreed outcomes rather than enforcement of codes and standards. Regulations should also address the need to monitor operating conditions and assessment throughout the life of the IoT applications.

6.2 Cyber-security

Considerable attention has been paid recently to the risks of “hacking” into connected and smart devices. In an age of growing tension and mistrust, the risk of an external party causing the software to fail is a very real and present danger. IoT-enabled applications have a high level of connectedness to networks and devices and their surroundings. Therefore, security issues need to be carefully considered during the introduction of new applications. Regulators need to liaise with manufacturers and stakeholders to ensure an appropriate level of protection from unauthorised access, control or interference for these applications. The issue that must be resolved with any smart system becomes when this system fails, how much of the smart mobility system will it take with it. Delays in rolling out the supporting infrastructure (both cyber and physical) to address these issues will undermine the potential of the technology in unlocking value for travellers and applications users.

6.3 Software Resilience and Redundancy

While the intention is for IoT-driven smart mobility to improve the resilience of transport services by responding to disruptions in real time, its operations will be dependent on the quality decision making software and digital networks that support these applications.[52] As more items are added to existing IoT platforms, the likelihood of a software malfunction or error increases.[53] If not designed adequately, failure at one point in the chain will have flow-on considerations for the rest of the smart cities infrastructure.[54]While system redundancy can help address these issues of software resilience, the prohibitive cost of establishing duplicate technology and sensor infrastructure remains a barrier.

6.4 Privacy

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[49] Neumann, C. 2015. Big data versus big congestion: using information to improve transport. *Mckinsey & company*.
[50] Crist, P., Greer, E., Ratti, C., Humanes, P., Konzett, G., Tijink, J., Figuero, D. & Lax, R. Big data and transport: understanding and assessing options. 2015. International transport forum data base.
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Kornhauser, A., Chang, A., Clark, C., Gao, J., Korac, D., Lebowitz, B. & Soboda, A. 2013
[54]Ibid,.

Today, personal data is created, transmitted, tracked and recorded across multiple platforms. The level of detailed, real time, location-based data that is so valuable for smart mobility also represents the biggest cause for concern. Governments and regulators recognise this – unlocking the full benefits of smart mobility requires a high level of data interconnectedness. This, however, can only be realised by the creation of a single decision making entity with direct access to all data e.g. a City Operations and Control Centre such as Rio's City Control Centre in Brazil.[55] But it is the creation of such urban intelligence centres that will have the greatest potential loss of individual privacy.[56] Hence, it is the responsibility of the operators and decision makers to run these centres with transparency (Neumann, 2015). For citizens to obtain the full benefits of IoT-enabled smart mobility, they need to be able to feel that their data is safe.[57]

7.0 Future Directions and policy considerations

Moving forward, it is important to embark on a national vision and start to formulate policies and strategies to enable widespread deployment. There are many lessons that can be learnt from countries, which have been successful in the implementation and deployment of smart mobility systems (e.g. Singapore, South Korea, and Japan). These learnings are mainly around the success factors that will lead to adoption and acceptance of smart mobility solutions and include:[58]

Vision and Strategy. This requires a national level commitment and recognition of the role of IoT and digital innovations in enabling smart cities and smart mobility outcomes. This can be achieved through development and ownership of a clear vision supported by meaningful strategies linking such applications to national long-term strategies for addressing congestion and road safety. Such national initiatives will need the support of relevant stakeholders. Governments can play a big role in convening stakeholder consultations and encouraging trials and demonstration projects.

Partnerships. This requires strong collaboration between the public and private sectors. This can include co-development of platforms to allow stakeholders, including government, industry and academia, work together.

Private Investment. Governments at all levels need to forge partnerships with the industry and create engagement platforms to encourage the private sector to develop value-added products and services.

Standardisation. To enable widespread deployment and adoption, national architectures and standards need to be established. These would provide the basis for interoperable IoT applications, and deliver consistent and cost-effective services. A good example in Australia is the establishment of common standards for electronic toll collection, which have facilitated the use of a single in-vehicle tag for all tolled roads in Australia.

Research and Development. Advancement of IoT applications will not reach critical mass until there is a strong commitment to funding of research and demonstration projects. This

[55] Ibid,.
[56] Ibid,.
[57] Crist, P., Greer, E., Ratti, C., Humanes, P., Konzett, G., Tijink, J., Figuero, D. & Lax, R. Big data and transport: understanding and assessing options. 2015. International transport forum data base.
[58] Dia, H. 2017. Digital innovations and smart mobility: mapping the value beyond the hype. *Low carbon mobility for future cities: principles and applications.*

funding does not need to come from governments only. The private sector can also play an important role in funding relevant research. Research organisations need to develop stronger engagements with the industry and capitalise on opportunities to commercialise research outcomes for the benefit of society.

Trials and Demonstration Projects. Collaboration between different stakeholders should aim to allocate funding to support IoT-enabled smart mobility test-beds and proof of concept projects. This approach will help to demonstrate the benefits and limitations of the technology. Lessons learned can be used to inform the next stages of development and widespread deployment.

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