Development and Evaluation of Models for Autonomous Shared Mobility-on-Demand Systems

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Abstract

This paper presents a research framework for the development and evaluation of new methods to provide urban transport that offer efficient, affordable and flexible trips while reducing reliance on private vehicle use. Specifically, the paper outlines a research project which aims to demonstrate novel uses of low carbon mobility solutions driven by disruptive forces which are changing the mobility landscape and providing consumers with more choices to meet their transport needs. These forces include vehicle electrification, automated self-driving and on-demand shared mobility services. The focus of this research is on understanding the factors influencing the acceptance and demand for mobility under these emerging forces, development of models for understanding the demand for travel in the age of connected mobility, and assessing their impacts particularly under scenarios of autonomous or self-driving on-demand shared mobility. The successful completion of this research will result in the development of rigorous models that provide a better understanding of the likely reduction in carbon footprint which these trends are likely to achieve for future urban mobility. This paper also provides some initial results from a pilot study on a small road network. The results showed that autonomous mobility reduced the number of required vehicles by more than 40% while still meeting the same demand for travel on the road network, compared to a base scenario with conventional cars only. The autonomous mobility also reduced the need for car parking space (by around 58% compared to the base-case scenario). Such an impact has a clear influence on urban form in our cities and could free up a substantial amount of land and space that can be used for other purposes. However, the simulation also showed that the total vehicle-kilometres travelled by the autonomous vehicles increased because the vehicles needed to reposition. Finally, the paper describes the remaining challenges that need to be overcome in this research, and outlines the next steps to achieve the desired outcomes.

Introduction

As part of a more interconnected world, our cities are playing an increasingly active role in the global economy. According to the McKinsey Global Institute (MGI, 2011), just 100 cities currently account for 30 percent of the world's economy. New York City and London, together, represent 40 percent of the global market capitalisation. In 2025, 600 cities are projected to generate 58 percent of the global Gross Domestic Product (GDP) and accommodate 25 percent of the world's population. The MGI also expects that 136 new cities, driven by faster growth in GDP per capita, will make it into the top 600 by 2025, all from the developing world, 100 of them from China alone. The 21st century appears more likely to be dominated by these global cities, which will become the magnets of economy and engines of globalisation.

The Challenges: Urban Growth, Ageing Infrastructure and the Cost/Funding Problems

Whilst this urban growth will be largely driven by economic development and the search for a better quality of life, the resulting success will dramatically change the scale and nature of our communities, and put a tremendous strain on the infrastructure that delivers vital services like transport, electricity, water, and communications. Today, more than half the world's population lives in towns and cities and the percentage is growing. By 2050, 70 percent of the world is expected to live in cities and urban areas. Already, ageing infrastructures in many cities are at a breaking point with governments' budgets for major infrastructure projects under increasing pressure.

Take for example the reform of urban mobility which remains one of the biggest challenges confronting policy makers around the globe. According to the United Nations Road Safety Collaboration (UNRSC 2016), it is estimated that 1.3 million people are killed on the world's roads each year. If left unchecked, this number could reach 1.9 million fatalities worldwide by 2020. The human cost is profound – unimaginable suffering and grief. The economic cost is also a staggering $100 billion a year in developing countries alone. The World Health Organisation (WHO 2015) has described road casualty figures as being of 'epidemic' proportions, with road-related trauma being the biggest single killer of those aged between 15 and 29. Over 90% of road crashes are associated with human error imposes a hefty amount of damages in terms of human and economic (International Transport Forum [ITF] 2014). It has also been estimated that the social, economic and environmental costs of avoidable congestion account for more than 1 percent of the GDP across the European Union (European Commission [EC] 2011), and currently cost the United States more than $115 billion each year (Intelligent Transportation Society of America [ITSA] 2016)

A number of studies reported in the literature have documented evidence showing that the environmental footprint of traditional transport systems, and in particular private vehicles with combustion engines, is not sustainable (ITF 2010). Globally, transport sector accounts for 27 percent of the world's total energy consumption 75 percent of which is sourced from non-renewable fossil fuels. Australia's per capita CO2 emissions are almost twice the OECD average while transport contributes 14 percent of GHG emissions (ACOLA 2015). Moreover, road traffic continues to account for around 80 percent of transport CO2 emissions and is estimated to reach 9,000 Megaton per year by 2030 if the current mobility trends are not curbed (ITF 2010).

Pursuing conventional mobility trends with emphasising on building new infrastructure in order to respond to demand increase would result in a vicious cycle depleting resources while failing to achieve sustainable transport systems.

The Opportunities

Decision makers and leaders who run these complex cities are increasingly recognising the role of smart technologies in improving the efficiency of existing infrastructure and sweating of assets through better utilisation of available infrastructure (Dia 2013). These systems can significantly improve operations, reliability, safety, and meet consumer demand for better services with relatively small levels of investment. Cities are essentially made up of a complex network of systems that are increasingly being instrumented and interconnected, providing an opportunity for better infrastructure management. An "Internet of Things" comprising sensors, monitors, video surveillance, and radio frequency identification (RFID) tags, all communicating with each other to enhance infrastructure capability and resilience, and capturing volumes of data. Through data mining, artificial intelligence and predictive analytics tools, smart infrastructure systems can help city managers to monitor the performance of vital infrastructure, identify key areas where city services are lagging, and inform decision makers on how to manage city growth and make our cities more liveable (Dia 2013).

New Paradigm: Technology-Driven Urban Infrastructure

Smart cities of the future will include advanced network operations management and control systems that utilise field sensors to detect and respond quickly to equipment and infrastructure faults. Vital infrastructure downtimes will be cut using sensors that monitor the health of critical infrastructure, collect data on system functioning, alert operators inside an integrated urban control centre to the need for predictive maintenance, and identify potential breakdowns before they occur. In transport, smarter vehicles, trains and public transport systems will sense their surrounding environments, and slow down or stop without human intervention in emergency situations. On-board public transport, a range of GPS, position fixing, video surveillance, and communications equipment will provide accurate and reliable multi-modal real-time passenger information, resulting in better informed travellers and ensuring a smoother, safer and more reliable experience for customers. A combination of sensors and position fixing equipment will maximise the efficiency of existing roads by providing route and network-wide levels of priority for emergency vehicles, light rail, and other modes of transport so as to maximise the movement of goods and passengers safely and efficiently. Back-office systems that leverage sensors, web, mobile, and GPS technologies will utilise smart algorithms, data mining and predictive modelling tools to reduce delays to passengers by optimising schedules and capacities in real time. Near railroad level crossings, a range of train-to-infrastructure and train-to-vehicle technologies will improve passenger safety by detecting fast approaching vehicles and providing warnings to avoid collisions. Electric vehicle charging infrastructure will also be integrated into a smart grid network, providing consumers with access to sustainable and equitable forms of connected mobility. A combination of technologies and sensors will also improve safety and security by permitting operators to remotely disable or enable a public transport service in the event of a security threat (e.g. an unauthorised driver).

Adoption of technology-based customer-centric approaches have the potential to introduce substantial improvements in customer satisfaction, and create a shift in attitude to cost and value. A smarter city will mean better access to sustainable forms of transport; electricity and drinking water that can be counted on; and energy-efficient buildings resulting in enhanced standards and quality of life for today's increasingly empowered citizens and consumers. Given the maturity levels and affordability of smart technologies, these benefits can be achieved at a fraction of the cost of investment in new infrastructure. In a study published in 2009, Access Economics reviewed the potential economic benefits from the adoption of smart technologies in transport, electricity, irrigation, health, and broadband communications. The report examined how smart systems will allow the use of vast amounts of data collected in all areas of city activity far more effectively, providing the potential to radically alter our economy and society for the better. Their research demonstrated that smart technologies would have significant benefits including a 1.5 percent increase in GDP, and increase in the net present value (NPV) of GDP by $35-80 billion over the first ten years. In another report prepared by The Climate Group (Global e-Sustainability Initiative [GeSI] 2008) on behalf of the Global e-Sustainability Initiative, it is estimated that a 15 percent reduction in emissions can be realised in 2020 through smart technologies that achieve energy and resource efficiency using adaptive and proactive technologies. In Australia, the challenges are further amplified by the fact that around 96 percent of Australian total energy consumption is made up of non-renewable resources, while its fuel stocks hold no more than three weeks' worth of oil and refined fuels onshore. Given that Australia's transport system accounts for 26 percent of whole Australia's energy consumption (ACOLA 2015), the reform of urban mobility becomes more crucial.

The convergence of physical and digital worlds is creating unprecedented opportunities to enhance the travel experience for millions of people every day through new mobility solutions driven by disruptive forces and providing consumers with more choices to meet their transport needs. Although some of these disruptive forces are still a few years away (e.g. driverless vehicles), they have already started to shape a vision for a mobility transformation driven by six key converging forces: Vehicle electrification, automated self-driving, mobile computing, on-demand shared mobility services, Big Data and predictive analytics. The coming together of these powerful trends is shaping an urban mobility future inspired by a vision of low carbon living and zero road injuries. In particular, there has been some enthusiasm recently surrounding autonomous and semi-autonomous driving and the shared economy. Shareable networks of autonomous electric vehicles, in particular, are reported to hold great promise for addressing the urban mobility challenges and promoting sustainable transport. Autonomous mobility-on-demand (AMoD) systems are novel and transformative mode of transportation aimed at reducing carbon emissions as well as vehicle accidents. However, principal challenge for researchers is to ensure the same benefits of privately-owned cars in parallel with cutting down reliance on non-renewable resources, minimizing pollution, and decreasing the need for constructing new roads and parking spaces (Pavone 2015). Furthermore, key to the success of these systems is a good understanding of the role of enabling technologies and new business models in improving the efficiency urban mobility and meeting people's demand for travel through low carbon mobility solutions. These systems can significantly improve operations, reliability, safety, and meet consumer demand for better services with relatively small levels of investment.

The work reported in this paper is part of a research project which is fundamentally an investigation into the development and evaluation of new methods to provide urban transport and active travel options. These new mobility solutions would offer travellers with more choices and provide efficient, affordable and flexible trips while reducing reliance on private vehicle use and promoting low carbon mobility.

Research Aims and Objectives

The aim of this research is to tackle current mobility challenges including environmental footprint and human casualties ensuing from private car usage in urban areas. This includes looking into innovative low carbon mobility solutions driven by disruptive technologies which are changing the mobility landscape and generating new opportunities for the consumers to meet their transport needs.

The main objectives of this research are as follows,

1. Undertake stakeholder consultation and institutional analysis through conduct of on-line and face-to-face surveys with individuals representing a broad range of cross generational consumers, transport providers, community groups and other key stakeholders – aimed at understanding the drivers of travel behaviour given emerging information technology solutions. This component of the work will also

identify the barriers and opportunities for greening urban travel through interviews and workshops with key stakeholders to guide the development of feasible interventions.

2. Development of models for demand forecasting and understanding the demand for travel in the age of connected mobility.
3. Development of models to assess the impacts of new and emerging low carbon mobility solutions (including autonomous on-demand shared mobility), and estimating how future carbon emissions can be best mitigated using the proposed intervention measures.

This paper is focused mainly on objective number 3, development of models for evaluating the impacts.

Literature Review

Providing access to high-quality urban transport services requires a variety of planning and operational innovations, as well as better understanding of travel behaviour, operational processes, and the factors which affect these issues. A growing body of literature over the past few years have addressed the issues of disruptive technologies and their future potential. In this section of the paper, we provide a high level review of some of these technologies and discuss a number of overseas studies which have attempted to evaluate their impacts.

Demystifying disruptive technologies

New technologies are poised to revolutionise the way in which communities interact with their daily issues including mobility needs. Autonomous Vehicles (AVs), Mobile Internet, Internet of Things (IoT), Cloud Technology, and Energy Storage are seen as the key drivers of smart urban transport systems.

- **Autonomous vehicles.** An autonomous vehicle is one that can manoeuvre with reduced or no human intervention (Manyika et al. 2013). The main contributions of these vehicles are reductions in greenhouse emissions as well as reducing road car crashes. Vehicle automation has a great potential for decreasing these numbers by removing the weakest link, the human driver, from the driving equation.

- **Mobile computing.** Today, people are taking advantage of smart phones for their daily trips as well using a multitude of mobile apps for monitoring the traffic volume on roads, finding the arrival and departure time of public transport systems and choosing the shortest route to their destination. Moreover, smart phones are a great source for obtaining real-time traffic information. Network-based solutions, which rely on passive monitoring of data already being communicated in the mobile phone system, have the potential to provide network-wide travel time and origin–destination information (Rose 2006).

- **Big Data.** Big Data refers to the large amounts of real-time data that is being generated from millions of connected devices and interactions including data from social media, card readers, navigation systems and so forth. Every day almost 2.5 quintillion bytes of data are created (Wu et al. 2014) including tweets on various topics and vehicles travelling from one point to another. Harnessing such a flow of data will benefit a multitude of sectors including transport systems. Urban areas are equipped with many sensors and actuators collecting information from different aspects of city dwellers' activities. Smart phones with built-in GPS systems can record and transmit their own trails. Transponders can be used to monitor throughput through a road network, measuring vehicle flow along a road or the number of empty spaces in a car park, and track the progress of buses and trains along a route. These devices and sensors provide urban managers with dynamic, well-defined and relatively cheap data on city activities enabling them to establish real-time analytics and adaptive management and governance systems (Kitchin 2014).

- **The Internet of Things (IoT)**. The IoT refers to the use of sensors, actuators, and data communications technology, built into physical objects from roadways to pacemakers, to enable these objects to be tracked, coordinated, or controlled across a data network or the Internet (Manyika et al. 2013). IoT is a key element for intelligent transport systems powered by many sensors and actuators embedded in vehicles, pavements and traffic lights to exchange real-time information among one-another to create a sustainable efficiency across the transport network.

- **Cloud computing.** Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction (Mell & Grance 2011). With the support of cloud computing technologies, it will go far beyond other multi-agent traffic management systems, addressing issues such as infinite system scalability, an appropriate agent management scheme, reducing the upfront investment and risk for users, and minimizing the total cost of ownership (Li et al. 2011).

- **Energy storage systems.** These convert electricity into a form that can be stored and converted back into electrical energy for later use, providing energy on demand (Manyika et al 2013). Lithium batteries are widely used in small applications, such as mobile phones and portable electronic devices. This type of batteries attracts much interest in the field of material technology and others, in order to obtain high power devices for applications like electric vehicles and stationary energy storage (íaz-González et al. 2012).

Autonomous mobility-on-demand (AMoD)

Several recent studies which relied on millennial surveys report that younger people are less keen to own private cars. In a study by car sharing company Zipcar, it is reported that half of millennials interviewed say they would prefer public transport and car sharing systems to privately owned cars (Zipcar 2014). With this in mind, shareable autonomous electric vehicles (particularly those in which electricity is produced through clean resources e.g. wind turbines or solar systems) appear like a promising proposition for decreasing the overall number of private cars. This would in turn directly address the problems of oil dependency, pollution, promote higher utilization rates and reduce parking lot sprawls (Zhang et al 2015).

To date, few studies have dealt with the implications of AMoD systems. Some of the studies of particular relevance to this research are described below.

Lisbon

The Lisbon study (ITF 2015) examined the potential impacts that would result from the implementation of a shared and fully autonomous vehicle fleet. To perform this assessment, the researchers developed an agent-based model to simulate the behaviour of all entities in the system: Travellers, as potential users of the shared mobility system; Cars, which are dynamically routed on the road network to pick-up and drop-off clients, or to move to, from, and between stations; and Dispatcher system tasked with efficiently assigning cars to clients while respecting the defined service quality standards, e.g. with regard to waiting time and detour time.

The analysis was based on a real urban context, the city of Lisbon, Portugal. The simulation used a representation of the street network, using origin and destination data derived from a fine-grained database of trips on the basis of a detailed travel survey. Trips were allocated to different modes: walking, shared self-driving vehicles or high-capacity public transport. A set of constraints were established (e.g. that all trips should take at most 5 minutes longer than today's car trips take for all scenarios, and assumed all trips are done by shared vehicles and none by buses or private cars). The study also modelled a scenario which included high-capacity public transport (Metro in the case of Lisbon).

The study modelled two different car-sharing concepts, "TaxiBots", a term the researchers coined for self-driving vehicles shared simultaneously by several passengers (i.e. ride sharing), and "AutoVots", cars which pick-up and drop-off single passengers sequentially (car sharing). For the different scenarios, the researchers measured the number of cars, kilometres travelled, impacts on congestion and impacts on parking space.

The results indicated that shared self-driving fleets can deliver the same mobility as today with significantly fewer cars. When serviced by ride-sharing TaxiBots and a good underground system, 90% of cars could be removed from the city. Even in the scenario that least reduces the number of cars (AutoVots without underground), nearly half of all cars could be removed without impacting the level of service. Even at peak hours, only about one third (35%) of today's cars would be needed on the roads (TaxiBots with underground), without reducing overall mobility. On-street parking could be totally removed with a fleet of shared self-driving cars, allowing in a medium-sized European city such as Lisbon, reallocating 1.5 million square metres to other public uses. This equates to almost 20% of the surface of kerb-to-kerb street area (or 210 football pitches!)

These findings suggest that shared self-driving fleets could significantly reduce congestion. In terms of environmental impact, only 2% more vehicles would be needed for a fleet of cleaner, electric, shared self-driving vehicles, to compensate for reduced range and battery charging time.

Stockholm

In the Stockholm study (Rigole 2014), the assessments included both a fleet consisting of currently in use gasoline and diesel cars as well as electric cars. The results showed that an autonomous vehicle-based personal transport system has the potential to provide an on-demand door-to-door transport with a high level of service, using less than 10 % of today's private cars and parking places. In order to provide an environmental benefit and lower congestion the autonomous vehicle would require users to accept ride-sharing, allowing a maximum 30% increase of their travel time (15% on average) and a start time window of 10 minutes. In a scenario where users were not inclined to accept a lower level of service, i.e. no ride-sharing and no delay, empty vehicle drive will lead to increased road traffic increasing environmental impacts and congestion. In a scenario which looked at electric cars, an autonomous vehicle-based system and electric vehicle technology seemed to provide a “perfect” match that could contribute to a sustainable transport system in Stockholm.

Austin

The Austin case study (Fagnant et al. 2015) investigated the potential travel and environmental implications of autonomous shared mobility systems by simulating a 12-mile by 24-mile area in Austin, Texas. The Multi-agent transport simulation (Matsim) software was used for conducting this experiment using 100,000 randomly drawn person-trips out of 4.5 million Austin’s regional trips. The study claimed that each autonomous shared car would almost replace around 9 conventional vehicles within the 24-mile by 12-mile area while providing the same level of service, but would generate approximately 8 percent more vehicle-mile travelled. Their study also confirmed that this system would decrease the emissions by not only replacing the heavier vehicles with higher emissions rates, but also by cutting down on the number of cold starts.

New York

The New York case study (Shen and Lopes 2015) introduced the Expand and Target algorithm which was integrated with three different scheduling strategies for dispatching autonomous vehicles. The study also implemented an agent-based simulation platform and empirically evaluated the proposed approaches using New York City taxi data. Experimental results demonstrated that the algorithms significantly improve passengers' experience by reducing the average passenger waiting time by around 30% and increasing the trip success rate by around 8%.

The work reported in this paper and which is being undertaken as part of the wider study will build on the findings and learnings from these studies by developing models that can be used in the Australian context.

Modelling Framework

This research will apply the Commuter model, which is an agent-based simulation (nano-simulation) tool, to model an AMoD system for the city of Melbourne. Most of the case studies reported before have utilised different types of agent-based models for assessing the impacts of disruptive transport technologies including autonomous vehicles, car-sharing, ridesharing e.g. (Boesch & Ciari 2015) and (Ciari et al 2015). A brief overview of the agent-based models and why they are suitable for this research is provided next.

Agent-Based Modelling

Transport professionals today have access to powerful modelling tools which can be applied at a number of levels depending on the application and modelling need. At the highest level are macro-simulation (or macroscopic simulation) tools which model traffic on a network as a time-varying flow on each link and assume that traffic streams generally follow behaviours similar to fluid streams. These tools are useful for building strategic, regional or city-wide models without attention to individual traveller behaviour. At the next level are dynamic simulation tools which include mesoscopic, microscopic and hybrid models. These dynamic models allow greater levels of detail than a strategic model. In the Mesoscopic approach, the vehicles are modelled as individual entities with simplified behavioural models (car following and lane changing) with a slight loss of realism resulting in an event-oriented simulation approach. Microscopic simulation offers the highest level of detail and allows for distinguishing between the different types of vehicles and drivers. It also enables a wide range of network geometries (e.g. freeways, arterials) and traffic control (e.g. traffic signals, give-way intersections and ramp metering) modelling. The behaviour of each vehicle is continuously modelled using detailed car following, lane changing, and gap acceptance models. In the Hybrid approach, the simulation concurrently applies the microscopic models in certain selected areas and the mesoscopic models in the rest. This approach can be used in large-scale networks where there is a need in specific areas to have a level of microscopic detail but with a global network evaluation.

While these modelling tools have served the transport profession very well in previous years, the recent digital disruptions in mobility solutions (e.g. app-based on-demand car sharing and ride-sharing) and the anticipated arrival of autonomous vehicles over the next few years have created visions for a very different future based on shared autonomous mobility. Fleets of autonomous vehicles, to be owned by commercial companies, would pick up passengers on demand and offer both car-sharing and rider-sharing services (Fagnant and Kockelman 2014;

OECD 2015; Rigole 2014 and Shen and Lopez 2015). This research build on previous studies and will investigate how these disruptions are likely to impact on utilisation of vehicles, car ownership, congestion, emissions and pollution. Modelling the impacts of such scenarios requires a level of detail much greater than what is offered by the above modelling tools.

Agent-based or nanoscopic modelling offers a number of features which would allow for modelling network performance using end-to-end trips made by travellers over multiple modes of transport, rather than single-mode trips made in a vehicle or walking. This approach also allows for modelling individual traveller behaviour including dynamic decision processing incorporating a dynamic mode-choice function of individual travellers. This provides new capabilities to allow a traveller in the model to make instantaneous choices between available modes as well as choices between available routes. For instance, consider a traveller in the model who initially intended to walk to a bus stop and take the bus to her destination. On arriving at the bus stop, the information display advises that the bus is running late as a result of traffic congestion. The traveller, depending on her delay tolerance threshold, may decide to request an autonomous car share or ride-share using her smartphone app. Although existing micro-simulation tools can model dynamic route choice within a mode, the demand is specified by an (O-D) matrix of mode-specific trips making it impossible to model a person dynamically switching from one mode of transport to another. A nano-simulation model can represent dynamic mode switching by allowing each individual agent to choose a new mode of transport during its trip (Duncan, 2010).

Data requirements

The travel demand data for this study will be sourced from the Victorian Integrated Survey of Travel and Activity (VISTA), which is an ongoing survey of travel and activity in Victoria. It includes all personal travel activities across the Victorian state that occur from home to access various activities. The currently available data covers the period from May 2007 to June 2010, and includes 11,400 households for the metropolitan Melbourne (VISTA 2015). Households who complete the surveys are randomly selected from a listing of all residential addresses in the study areas. They are asked to fill in a travel diary for one specified day of the year. All personal travel outside the home is reported, from a walk around the block through to a trip interstate (VISTA, 2009). Collecting this information provides detailed picture of travel including distribution of trips, trip rate, median trip distance, median trip time, mode share of travel, main method of travel, etc. which helps the government make better transport and land-use planning decisions.

The traffic data, including traffic counts and signal timings, are available to the University through a Virtual Private Network (VPN) connection to VicRoads.

Pilot study

To develop a proof-of-concept, a pilot study is currently being conducted on a real transport network located in Melbourne (Stonnington area shown in Figure 1). The pilot aims to explore the feasibility of using Commuter for this project. It is also aimed at developing a better understanding of the capabilities of the tool and the various functionalities of the simulation program required to enable investigations of a vast range of AMoD scenarios across a much larger study area under real activity-based data sourced from VISTA. The pilot study area is shown in Figure 1 and Figure 2.

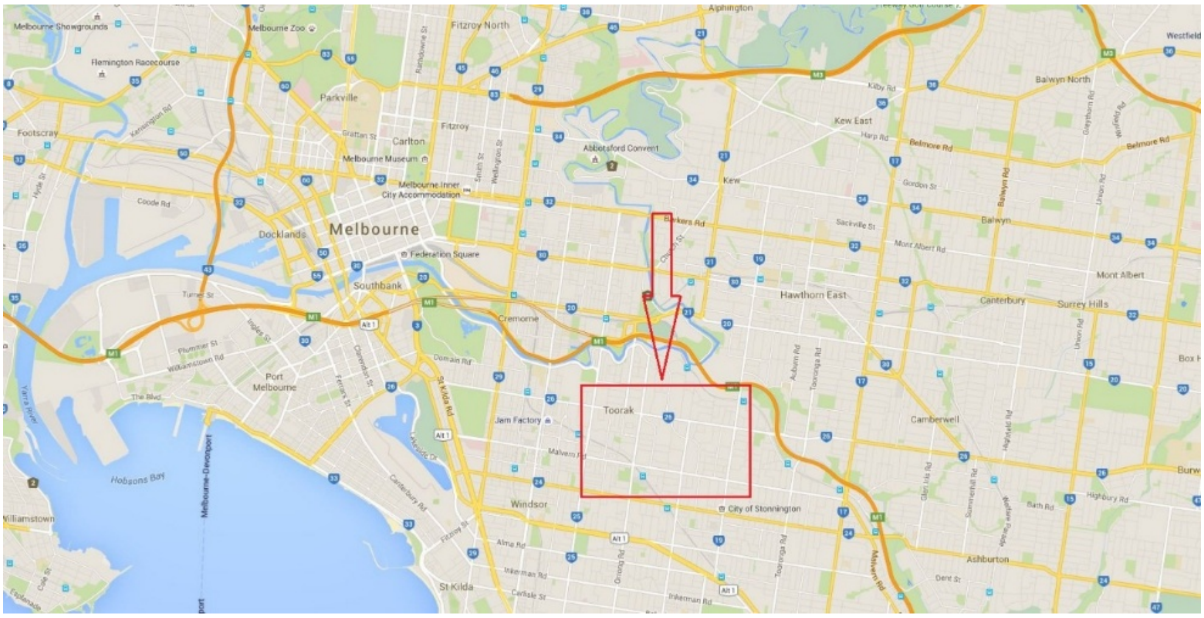

Figure 1: Pilot study area

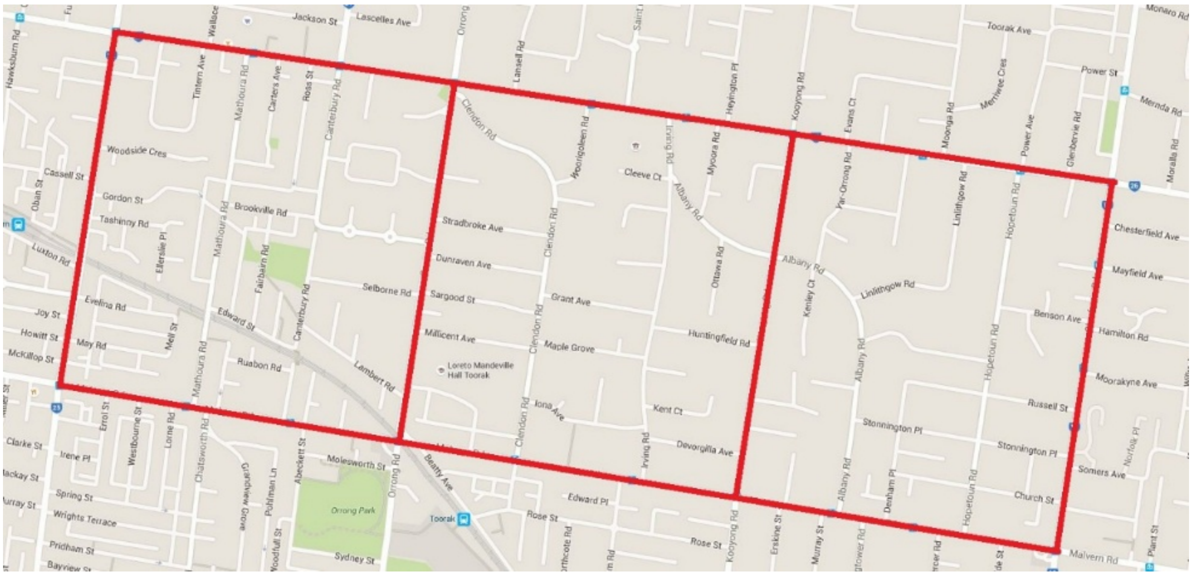

Figure 2: Major roads within pilot study area

Figure 3 shows the commuter representation of the Pilot area. The area features six origins (H1-H6), and three destinations (Work, Shopping Centre, Education) to which trips are made using the current transport system (Private vehicles). This represents the base scenario. The same network and demand will then be simulated using a fleet of shared autonomous vehicles and the two scenarios will be compared to determine the impacts. Note that the model incorporates signalised intersections which can be linked to the SCATS simulator allowing a more detailed level of realism in the simulation.

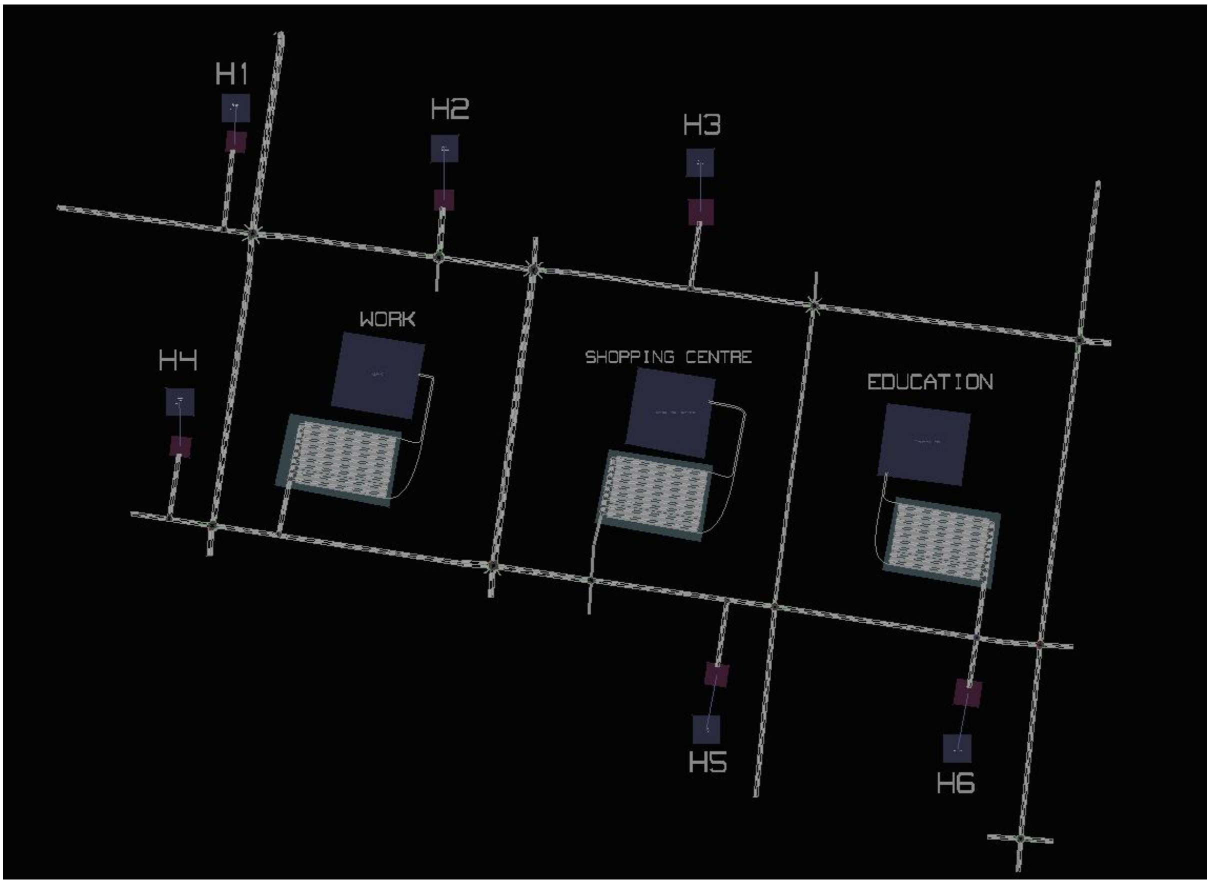

Figure 3: Pilot study area represented in Commuter

Autonomous shared mobility scenario

To date, a base case scenario and a scenario using a simple AMoD system have been developed in Commuter. In the base scenario, all trips are undertaken during the AM-Peak (7am-9am) using private cars. Table 1 describes the demand distribution among different origins and destinations.

Table 1: Total number of trips between different ODs during AM-Peak (7am-9am)

Origin \ Destination	Work	Shopping Centre	Education	Total
H1	100	120	89	309
H2	147	90	126	363
H3	125	100	109	334
H4	160	100	140	400
H5	120	160	100	380
H6	110	120	120	350
Total	762	690	684	2136

The information in Table 1 assumes single-car occupants and shows a base-case scenario with a total number of 2,136 privately owned vehicles. These vehicles would require around 25,632 square meter area as parking lots in the proximity of destinations. In the autonomous shared mobility scenario, privately owned self-driving cars and shared self-driving cars with capacities ranging from two to four people have been assumed and simulated. Twenty-five percent of people are assumed to be using privately owned autonomous cars, and the other seventy-five percent are assumed to travel in groups of two, three or four. In both cases, passengers would be picked up and dropped-off at their destinations by the autonomous vehicles. After dropping their passengers off, the privately owned self-driving vehicles head back to their starting point (Home) and wait for further instructions from their owners. The self-driving shared cars, on the other hand, would typically be owned by a commercial fleet company who would direct the vehicles to nearby waiting areas where they also would wait for further instructions.

An initial analysis of the autonomous mobility scenario (Table 2) shows that people travelling in groups and being dropped-off by the self-driving cars result in both decreased number of required vehicles (more than 40% compared to the base scenario) and parking space (around 58% compared to the base-case scenario). This frees up a substantial amount of land and space which can be used for different purposes. However, the simulation also showed that the total vehicle-kilometres travelled (VKT) by the autonomous vehicles increased by around 29% because the vehicles needed to reposition. The increase was largely due to the privately owned vehicles which were assumed to return to their starting point. Finally, it was assumed in this analysis that no public parking space was needed for the privately owned autonomous cars because they would wait at home rather than at a public parking space.

Table 2: Comparison of scenarios

Scenario name	Number of Vehicles on the road network (number)	Mean VKT travelled (Km)	Parking space required (m^2)
Base Case – Human-driven single-occupant vehicles	2,136	4.04	25,632
Autonomous Mobility	1,217	5.20	10,884
Percent Difference from Base-Case Scenario	43% decrease	29% increase	58% reduction

Summary and Future Directions

The pilot study reported in this paper aimed to demonstrate the feasibility of using the agent-based approach. Two simple scenarios were simulated on a real transport network to investigate the implications of AMoD. The results showed that incorporating shared driverless-cars can reduce the total number of vehicles required to meet the transport needs of a community. It also decreased the parking requirements which would free up this space for other purposes. The results, however, also showed that there are likely to be some negative impacts such as increased total kilometres of travel due to repositioning, but this can mitigated if all future self-driving vehicles are electric.

Although the pilot study has demonstrated the feasibility of the approach, there are still a large number of challenges that will need to be addressed in this research. These include:

- Undertaking stakeholder consultation and institutional analysis to develop a better understanding of the drivers of travel behaviour given emerging information technology solutions. The study also needs to identify the barriers and opportunities for greening urban travel o guide the development of feasible interventions.
- Development of models for demand forecasting and understanding the demand for travel in the age of autonomous and connected mobility.
- Development, calibration and validation of real-life nano-simulation models which include a large network and representative set of demands from the VISTA data. The models will also need to be tested on a large number of scenarios including ones which assume reduced or zero car ownership, to scenarios which assess the impacts under provision of light and heavy rail, public transport buses etc.

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