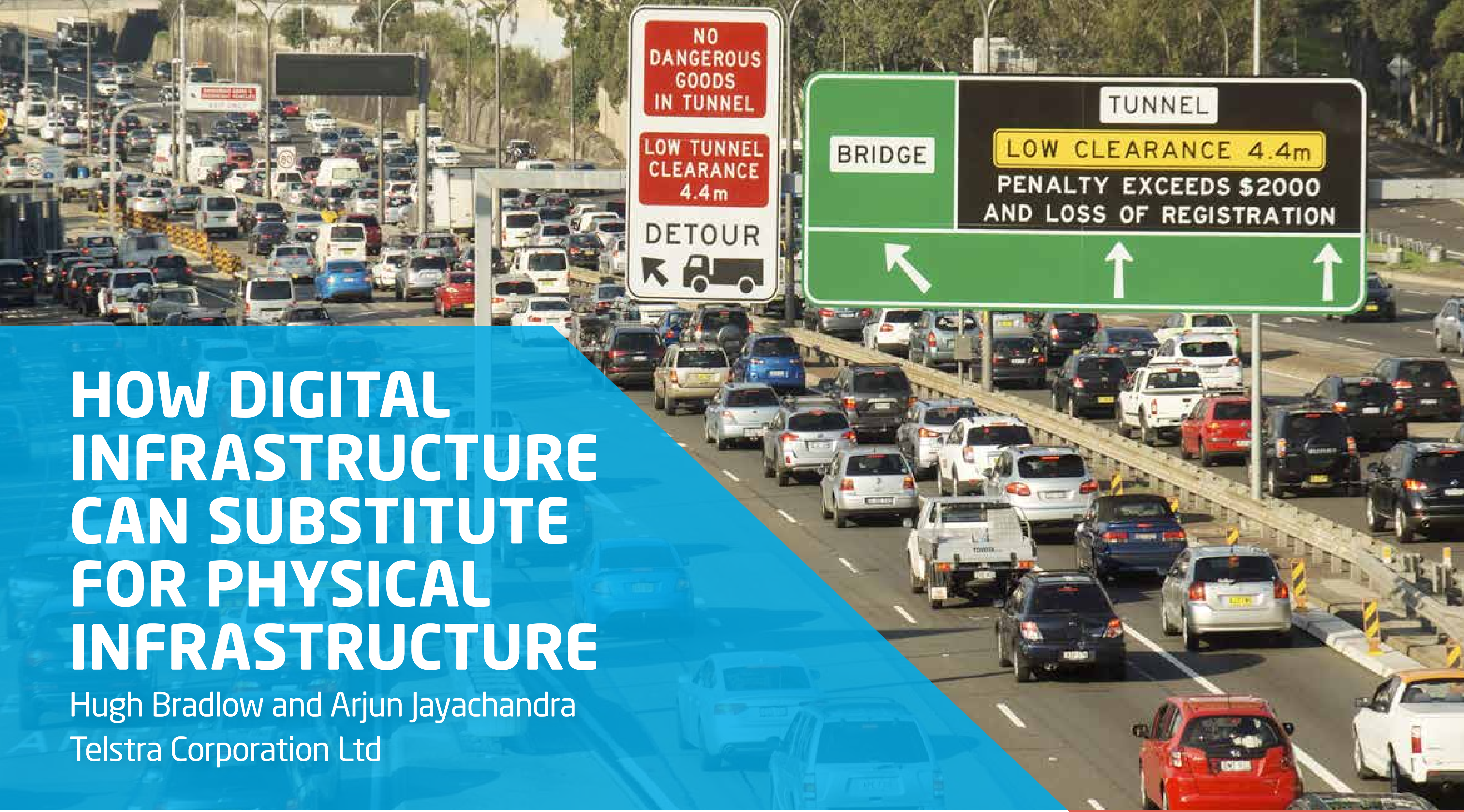

HOW DIGITAL INFRASTRUCTURE CAN SUBSTITUTE FOR PHYSICAL INFRASTRUCTURE

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ABSTRACT

Today digital technology is viewed as additive to the physical world: something that enhances but does not replace the use of physical infrastructure. However, this paper discusses the next wave of digital technology adoption that can potentially be substitutive for physical infrastructure. In particular, we examine the impact of emerging information and communications technologies (ICT) on the demand for roads over the next three to four decades. Australia's population is estimated to grow from 23.5 million in 2014 to 37.6 million in 2050. If we continue to build and operate roads as we do today we are likely to need about two and a half times more road capacity in 2050 than we have today, to cater for this population growth. However this paper estimates that, using a simple but realistic set of assumptions, the road capacity requirement in 2050 will be roughly equivalent to the capacity existing today. This is due to the combined impact of technology adoption over the next 35 years which is predicted to lessen the need to build new infrastructure, peaking at about 150 percent of today's capacity (as opposed to a 250 percent increase).

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This paper was presented by Dr Hugh Bradlow at the Low Carbon Transport on the Move Conference on 14 May 2015 (http://ussc.edu.au/events/past/Low-Carbon-Transport-on-the-Move). The conference was held in partnership with the NSW Government.

Convened by Dr Susan Pond, Adjunct Professor and Leader of the Alternative Transport Fuels Initiative at the US Studies Centre, the conference featured leaders from industry, academia and government, from the US and Australia. They brought into focus the technologies and policies required to support a sustainable transport system.

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1. INTRODUCTION

Over the next decade a number of transformative technologies that are now emerging will become mainstream. The term 'emerging technology' refers to technologies that exist today – either in laboratories or are being used by early adopters – but are not yet commonplace in the general population and thus there is little evidence of their transformative impact to date. The term 'mainstream' describes technologies that are used regularly by the majority of the population. The World Wide Web and web-centric fixed and mobile broadband communications are examples of technologies that are mainstream today.

Whether an emerging technology becomes mainstream or not is often very difficult to predict because it depends on human behaviour. As Isaac Newton once put it "I can calculate the motion of heavenly bodies but not the madness of people." However, our intent in this paper is not to predict which technologies become mainstream but rather to examine the potential impact of certain emerging ICT technologies on our society. To do this, we must assume that the emerging technologies relevant to this paper will become mainstream.

In Section 2 of this paper, we describe how technology can influence demand for road infrastructure. In Section 3, we quantify that influence using a simple but realistic, practical analysis. Finally in Section 4, we discuss the results and the conclusions that can be drawn for infrastructure planning.

1.1. Assumptions

It is not the intent of this paper to explain these technology developments but to begin with the realistic assumptions that the capabilities delivered by these technologies will meet expectations in terms of performance and affordability.

The technologies of interest can be grouped into two broad categories:

1. Immersive communications: which allow a very realistic 'telepresence' experience based on high definition video and high fidelity surround-sound audio carried over media-centric broadband networks.
2. Artificial intelligence: which allows the creation of totally new capabilities, such as autonomous vehicles, as well as the optimisation of infrastructure systems, such as roads.

The focus of this paper is on the impact of technology on road capacity, particularly for the arterial road system. Roads are a significant expense to any developed economy. In Australia in 2009 over $20 billion was spent on transport infrastructure[1]. Besides being expensive, road projects tend to be long term and highly disruptive, so it is critical that governments build no more than what is required. It is thus vital to know how much road capacity will be required over time and whether we can reduce the demand through the use of digital technologies.

2. HOW TECHNOLOGY INFLUENCES DEMAND FOR ROADS

We have adopted a two-step approach to evaluating how technology can influence demand for roads. First, in the next section, we extrapolated growth in road capacity for the four decades from 2010 to 2050 from the predictions for population growth and the number of vehicles per person. Second, we envisaged the alterations to the outcome of this extrapolation that could result from the technology developments described below in this section. In particular we consider three technology trends that may impact forecasts.

2.1. The sharing economy

The rise of the so-called "BroMoSo" technologies (Broadband-Mobile-Social) has led to new business models which are in the process of changing society. This decade has seen the rise of the sharing economy, examples of which include Airbnb, Zipcar, and Uber. The use of mobile Internet technology has enabled individual consumers to share their assets with others in order to maximise their utilisation.

Clearly the sharing economy has the potential to impact car ownership, as people see less need to own a vehicle because they are able to share someone else's through services such as Zipcar or Uber. While the impact of sharing on car ownership is relatively small today it needs to be modelled as it could grow over time.

2.2. Telecommuting

Cheaper and higher definition screens, wearable displays such as the Occulus Rift or Microsoft Hololens, and pervasive fixed and mobile media-centric broadband have the potential to enable telepresence connectivity across the country, thereby often obviating the need for collaboration to take place in an office environment. Inevitably this could lead to a rise in telecommuting and a further reduction in the use of the roads, particularly during rush hours. Rush hour demand is the key determinant for the amount of arterial road capacity required.

2.3. Autonomous Vehicles

As little as just over a decade ago, it was believed that it would not be possible to create a fully self-driving car[2]. Yet Google have created such a vehicle and it drove itself for over 1 million kilometres around California without an accident (other than two minor accidents, both of which were caused by a *human* driver, not the autonomous vehicle[3] – one caused by the human driver of the car following them, and one when the Google car was being manually driven[4]).

Autonomous vehicles have a significant impact on the road system, because they can react at machine speed and not human speed. This enables them to both avoid accidents and also to be packed more densely on the roads, as they do not need to leave a following distance from the car in front. It is this ability to effectively form road trains (i.e. to be following inches from the car in front at speeds of many 10's of km/hour) that enables autonomous vehicles to increase the capacity of roads.

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As mentioned, autonomous vehicles can use technology and communications to avoid accidents. It turns out that 90 percent of road accidents today are caused by human error[5], so autonomous vehicles could significantly reduce the annual road toll. Today, the average annual road toll in Australia is approximately 1,200 people[6]. In addition to the people killed, road accidents cause approximately 50,000 people to be injured seriously enough each year to require hospitalisation[7]. It is legitimate to assume that a fully autonomous road system could avoid nearly 90 percent of fatalities and injuries, thereby saving approximately 1,000 lives per year and avoiding 45,000 serious injuries. This would relieve the health system of a huge burden to say nothing of other impacts such as the drain on social services and police forces.

Now that the viability of self-driving cars has been proven, there is a rush amongst car manufacturers to build and market autonomous vehicles. A flurry of recent announcements would indicate that we can expect the market introduction of fully autonomous vehicles in about 2020, but in the meantime car manufacturers are already progressively introducing key aspects of autonomous vehicles –such as adaptive cruise control, lane assist driving, self-parking, collision-avoidance self-braking systems - into their production vehicles.

Needless to say, it will take some time for new fully-autonomous vehicles to diffuse into the market. Consumer Reports says that the average life expectancy of a motor vehicle is about eight years or 150,000 miles (roughly 241,000 kilometres), but that vehicles can go on for about 15 years[8]. However, it may also possible for drivers to fit existing cars with an aftermarket autonomous driving kit, such as those being tested by Cruise[9]. Because of the significant safety and societal benefits of autonomous vehicles it is not unreasonable to expect that at some point in the 2020s, developed countries could mandate a date by which all vehicles must be autonomous in order to be registered. This would lead to a more rapid introduction of self-driving cars than could be anticipated from natural diffusion alone.

3. ANALYSIS

The purpose of this section is to test the hypothesis that the technology trends discussed in Section 2 will influence the demand for road capacity. In performing this analysis we make certain simplifying assumptions which are explained below. However, the analysis is parametrically-based, allowing the sensitivity to the assumptions to be tested.

Note also that the analysis is based purely on the impact of cars on arterial roads. We have not considered the impact of the transport and logistics system because it is reasonable to assume that the rush-hour capacity (which determines the required road size) is dominated by commuter cars as opposed to trucks or public transport vehicles.

We have analysed the road capacity relative to the baseline capacity in 2014. All results are expressed as a multiple of this capacity.

We have analysed four separate scenarios as follows:

3.1. Do Nothing

We have based our calculations on the Australian population projection from the Australian Bureau of Statistics, which has forecast population numbers each year for the entire 21st century[10].

In addition to population growth, it is also necessary to understand the level of car ownership over time. We have adopted figures produced by Siemens[11] for 2011, 2020 and 2030, and used these as the basis for the car ownership levels from 2009 to 2050, based on a linear extrapolation. These figures are almost certainly conservative as they show per capita car ownership increasing from 0.76 (vehicles per person) in 2014 to 1.21 in 2050.

Based on the above figures, it is possible to estimate the additional road capacity to accommodate the additional vehicles that will result from the rise in vehicle ownership over the period to 2050. This assumes that there is no change in the way we operate vehicles and roads and that demand patterns do not change, hence the 'Do Nothing' moniker for this curve.

This curve is the basis for comparison with the next three curves which recognise the impact of technology on traffic demand.

3.2. Impact of Sharing Economy

The assumption is that shared vehicles will lead to a reduction in car ownership because convenient access to a shared vehicle will be cheaper than full-time car ownership. A study by SGS Economics and Planning for the City of Sydney[12] estimates that for each shared car, there would be a reduction of 12 cars on the road.

> For each shared car, there would be a reduction of 12 cars on the road

Data on the uptake of shared cars is more difficult to obtain and is influenced not only by demand but may also be constrained by the availability of suitable parking spaces for the shared vehicles. However, it is highly likely that this latter problem can be solved by people who no longer own cars sharing their car parking spaces, so we do not treat this as a constraint in our calculations.

The SGS study showed very little uptake to date in the City of Sydney. We have thus assumed that the sharing economy has had no impact on car ownership so far, but from 2015 there will be a 0.5 percent reduction in the number of vehicles per capita from the previous year. The number of vehicles per capita that our original estimate would have assumed for that year (the extrapolation above from the Siemens study) is then reduced by this percentage.

3.3. Impact of Telecommuting

Like any infrastructure or utility, capital investment in road capacity is determined by peak usage requirements. Telecommuting will lead to a reduction in those peak hour requirements. Data about telecommuting is sparse. An IBIS World report commissioned by IBM states that on average approximately one in eight people work from home on any given weekday[13]. However it is not clear how many of these people work from home *in addition* to working at a business location as opposed to *instead* of the business location. We have used the 12.5 percent figure as a starting point for the number of telecommuters in 2015 and assumed that each of these telecommuters avoids travelling to work on average once a week. We speculate that the number of telecommuters will have doubled to 25 percent of the workforce by 2050 and that on average they will spend three days per week at home. We have then applied linear extrapolation to determine the overall reduction in peak hour traffic.

3.4. Impact of Autonomous Vehicles (AVs)

This paper focusses on arterial road capacity. We assume that arterial roads have three lanes in each direction and that the road capacity is determined by the number of vehicles that can be carried per lane. We have adopted a figure of 2,000 vehicles per hour per lane (vphpl) for current vehicles from a study conducted by transportation planning consultants, Fehr & Peers[14]. The same study suggests that lanes devoted to autonomous vehicles would double that carrying capacity to 4,000 vphpl due to the ability to pack them more tightly together.

The rate at which AVs penetrate the market is dependent on technology advancement (which is rapid, as discussed in Section 2.3) and the impact of regulation. With regard to the latter, the laws governing AVs are still being developed but given the potential health implications, we believe governments are likely to become proactive in this regard. For the estimates in this study, we have assumed that the first fully autonomous vehicles will be introduced in 2020 and AVs will reach 100 percent penetration over the following 20 years (using a linear interpolation).

Obviously whole lanes cannot be devoted to AVs until the penetration of such vehicles is sufficiently large to warrant such an action, so our modelling has assumed that the number of three-lane highways must be the larger of the number required to support ordinary vehicles and the number required to support AVs where the latter have dedicated lanes. We have repeated this modelling assuming reservation of zero, one, two and three AV lanes. This then determines the optimal time to introduce lane reservation as well as the number of roads required. Because of this process, the curve is not smooth, since when an additional AV lane reservation is introduced this leads to a significant downtick in capacity.

4. RESULTS

The curves described in Section 3 are shown in Figure 1.

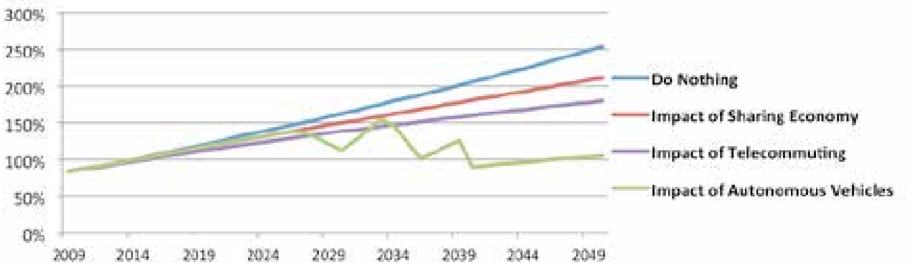

Figure 1: Road capacity growth in Australia (normalised to 2014 values)

The first and most startling conclusion from the curves of Figure 1, is that the 'Do Nothing' approach of continuing business-as-usual will lead to a demand for two and a half times the amount of road capacity over the next 35 years. However, the combined impact of the sharing economy, telecommuting and autonomous vehicles shows that road capacity levels in 2050 are approximately the same as today.

Both the sharing economy and telecommuting tend to flatten out the growth curve, but it is AVs that clearly can have the most significant impact on the demand for road capacity. In the interim period, while AVs penetrate the economy, road capacity would need to continue to grow to a peak of about 155 percent of the capacity in 2014 which we estimate to be reached in 2033. Thereafter road capacity requirements decline significantly due to the introduction of autonomous vehicles and the reservation of exclusive lanes for these cars.

As discussed in Section 2, the pace of introduction of AVs can be influenced by regulation. If AV penetration is allowed to diffuse more slowly (over a 30 year period from 2020 to 2050), the ultimate capacity required in 2050 will hardly be affected, but in the interim we shall need to build more road capacity to accommodate the intervening period (the maximum capacity will climb to 181 percent of today's levels as per Figure 2).

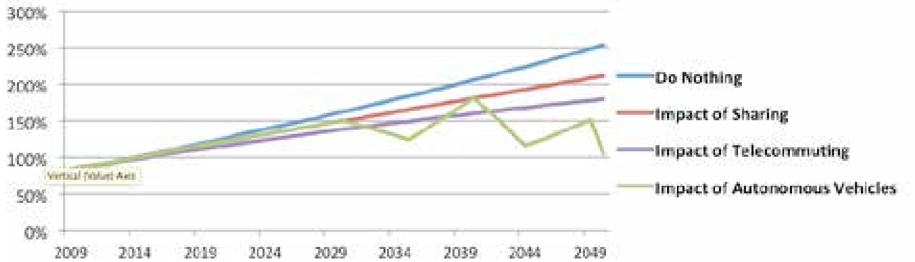

Figure 2: Road capacity growth in Australia (normalised to 2014 values) under the assumption that the AV penetration takes 30 years

Finally, given the somewhat ad hoc nature of the estimate of the decline in per capita vehicle ownership due to the sharing economy, it could be argued that this unduly influences the results. We accordingly tested the sensitivity of our assumption by halving the rate at which vehicles are removed from the roads to 0.25 percent from the previous year. The results in Figure 3 show that again, this has minimal impact on our overall conclusions.

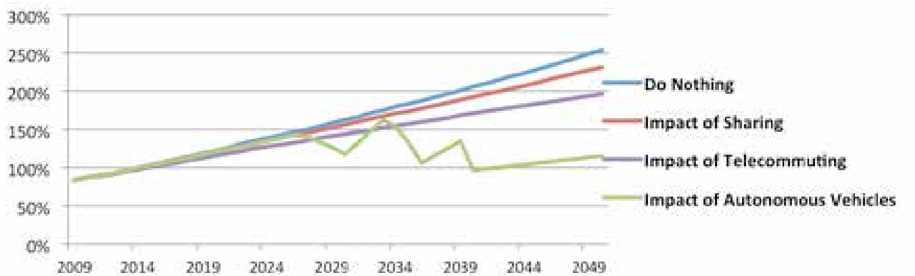

Figure 3: Road capacity growth in Australia (normalised to 2014 values) under the assumption that rate of sharing economy adoption is halved

5. CONCLUSION

Overall, this analysis shows that digital infrastructure will enable a significant reduction in investment in physical infrastructure. Today's emerging technology will almost certainly rapidly mature to the point where it enables fast penetration of autonomous vehicles in the 2020s, both for new and existing cars. Thus proactive and progressive government policy towards the adoption of AVs will avoid significant over-investment in road infrastructure and also deliver major savings to the health system.

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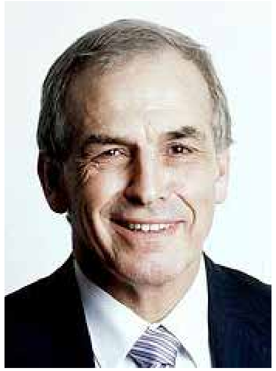

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