ENGN2226: Portfolio (2015)

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Topic: *Improving a Shared Autonomous Vehicle Network*

Abstract:

Autonomous vehicles are a transport mechanism designed to enhance the transport capabilities of traditional cars, while eliminating the need for a driver and promise many benefits for safety, road congestion, carbon emissions and parking. A shared autonomous vehicle network is where people share a fleet of autonomous vehicles similar to other car sharing programs like Uber, except without the human driver. This portfolio aims to improve a shared autonomous vehicle network using a systems engineering approach. Qualitative and quantitative analyses were conducted to determine community perceptions of driverless cars, providing a basis for further recommendations and innovations. Human factors demonstrated that many feel uncomfortable using a shared vehicle system, and would prefer to own their own car. Control factors found that using relocation strategies for vehicles significantly reduced waiting time. Using a variety of energy metrics, it was found that an SAV network was effective in reducing the environmental impact of automobiles. A cost benefit analysis demonstrated that investment in autonomous vehicles is highly cost effective to improve road safety and road congestion. Recommendations were allowing different sized vehicles in the SAV fleet, implementing relocation strategies to minimise wait time, and grouping passengers together based on similar journeys.

Summary of Systems Techniques Used	
Qualitative Methods	
Survey of ANU students and analysis of qualitative data	Sect. 2.2.1
Analysis of surveys and interviews in literature	Sect. 2.2.1
Quantitative Methods	
Population sampling, and error analysis of survey data	Sect. 2.2.1
Gathering quantitative data for cost benefit analysis	Sect. 2.1.4
Human Factors	
Improving ergonomics of SAV fleet	Sect. 2.2
Health and Safety – Hierarchy of Controls	Sect. 2.1.2
Time Factors	
Adapted PERT chart of typical commute with autonomous vehicle	Sect. 2.4.3
Behaviour over time (BoT) – Demand of Passengers	Sect. 2.3.1
Decreasing passenger wait time	Sect. 2.3.1, 2.4.3
Material Factors	
End of Life Issues of SAVs	Sect. 2.1.1
Energy Factors	
Comparison of different impact metrics	Sect. 2.1.1
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1 INTRODUCTION

1.1 Motivation

Convenient transport is a crucial part of a modern city. Since the advent of the automobile, the convenient and personal transport it provides has not been surpassed by any other form of like transport (Brownell 2013; Ford 2012). However, personal automobiles continue to be unsafe, polluting, congestion causing and expensive. Brownell (2013) described five criteria that a system would require if it were to surpass the traditional car. These are

1. Provide a solution to the congestion problem
2. Improvements in safety over traditional cars
3. Decreased environmental impacts compared with traditional cars
4. Be economically feasible
5. Convenience and comfort on par with traditional automobiles

A shared autonomous vehicle (SAV) model has the potential to meet all of these criteria, hence this has been an intensive research area over the past several years (Anderson et al. 2013). An SAV network has the ability to transform our transport system by reducing traffic, decreasing the number of accidents and reducing CO_2 emissions. However, there are still many areas of improvement required in this area, as will be discussed below.

1.2 Description of an Autonomous Vehicle (AV)

An autonomous vehicle (driverless car) is a car designed to offer the transport capabilities of a conventional automobile, except without human input. An AV possesses a variety of sensors to help guide through a road system, which can include LIDAR, video cameras, GPS and radar (Jiang 2015). The five levels of automation, defined by the National Highway Traffic Safety Administration (2013) are:

Level 0 – No Automation: Driver is sole controller of the vehicle

Level 1 – Function-specific Automation: Examples include automatic braking, cruise control and lane keeping

Level 2 – Combined Function Automation: At least two controls designed to work in unison, order to release the driver control of those functions. An example would be adaptive cruise control and lane centring operating in unison.

Level 3 – Limited Self-Driving Automation: Vehicle has full control of all ‘safety-critical’ functions, but driver may occasionally have to take control.

Level 4 – Full Self-Driving Automation: Complete control of the vehicle is automatic, with the driver only setting up destination instructions.

In this portfolio the primary focus will the level 4 category of automation, since this is space where a shared autonomous vehicle network would be most effective.

1.3 Description of a Shared Autonomous Vehicle (SAV)

A shared autonomous vehicle (SAV) functions the same as an autonomous vehicle (AV), except users rent vehicles from a pool of vehicles whenever they need them. Users will be able to order a SAV using their smartphone or computer. In this portfolio, we will assume that vehicles in an SAV fleet have level 4 automation.

2 SYSTEM ANALYSIS: OUTCOMES AND RECOMMENDATIONS

2.1 Outcomes of Implementing an SAV Network

2.1.1 Decreased Environmental Impact

Different energy metrics were compared to demonstrate the decreased environmental impact of an SAV network.

Chester and Horvath (2009) calculated that the average total energy use (including embodied energy and running costs) of an average light-duty vehicle to be 1230 GJ over its lifetime. Fagnant and Kockelman (2014) found that under their model, lifetime energy usage of a combustion engine autonomous vehicle was 1087 GJ, a modest reduction of 12%. This is tabulated in Table 1, along with comparisons to other studies.

Many energy factors metrics were considered to determine the possible environmental impact of the autonomous vehicle. Since AVs are still in the prototype and testing phase, accurate energy use data cannot be determined. Nevertheless, an order-of-magnitude approximation can be determined. Several studies using different metrics were compared in Table 1.

Table 1: Comparing of Environmental Impacts of AVs (adapted from Barcham 2014)

Metric	Effect Magnitude	Study
Fuel Economy	100% increase ~ 1000% increase	Anderson et al. 2013
Fuel Demand	91% decrease ~ 173% increase	Brown et al. 2014
Energy Use	12% decrease	Fagnant & Kockelman 2014
Greenhouse gas emissions	5.1% decrease	
Carbon Monoxide emissions	34% decrease	
Total Distance Travelled	11% increase	
Fleet Size	66% decrease	Spieser et al. 2014

Table 1 shows that the environmental effects of autonomous cars are for the most part positive, with the possible exception of total distance travelled, where Fagnant & Kockelman (2014) conducted a simulation and found that the total distance travelled for driverless cars increased by around 11%. This was mainly due to vehicles having to access their passengers. The carbon monoxide emission decrease of 34% is significant, and this is due to the considerable quantities of carbon monoxide emitted during vehicle starts. Cold starts of a vehicle exhume more carbon monoxide than hot starts (Faiz et al. 1996), and since SAVs are used for a greater proportion of the day then the number of cold starts is reduced, hence reducing the carbon monoxide emissions (Fagnant & Kockelman 2014). [In the simulation there were 0.054 cold-SAV starts per person-trip compared to 0.64 in the US currently (Kang & Recker 2009).] It is also likely that due to the increased use of the SAV, the life span may be considerably less than a conventional vehicle.

Some argue that the amount of material that is used to manufacture the AV could be reduced and some of the safety mechanisms could be removed, due to the increased safety of AV (Burns 2013). This has been the basis of the prediction of an upper bound of 1000% increase in fuel economy made by Anderson et al. (2013). Reducing the mass of the autonomous car is not recommended in the short term, and would only be feasible in the future, if the accident rate was very close to zero.

One of the main benefits of the introduction of an SAV network is the huge reduction in the number of cars that need to be owned. In the US, cars are only used 10% of the time (FHWA 2009), so if we can increase the rate of usage of vehicles, then the time 'wasted' by vehicles in their parking spaces will be reduced. Autonomous vehicles hope to increase the time in which cars are used, thereby decreasing the embodied energy to manufacture cars, as well as material waste. In an SAV model, even though fewer vehicles per person would need to be purchased initially, the replacement rate would be much higher (1.5-2 years), so the embodied energy would still decrease slightly (Fagnant & Kockelman 2014). However, based on the sheer number of cars produced, even a small decrease in proportion would actually result in a massive net decrease in embodied energy.

2.1.2 Safety Improvements

An increase in road safety is often stated as the main benefit of autonomous vehicles (KPMG 2013; Anderson et al. 2013). The number of road fatalities in Australia in 2013 was 1187 (BITRE 2013). While the number of road fatalities is low compared to many other developed countries, (International Traffic Safety Data and Analysis Group 2014), the financial cost to the community and in human tragedy is high, and so it is felt that this is a problem that needs addressing. Human error accounts for over 90% of crashes, and has been the case for a number of years (Ford 2014; NHTSA 2008; Treat et al. 1979).

From a workplace health and safety perspective, there are several ways to remove a hazard as shown in Figure 1. Current measures of increasing road safety include administrative controls and engineering controls. Administrative controls used presently used include driving tests, education about road safety and advertising. Suspension of licences, if drivers are caught breaking the law is an engineering control. Also airbags, crumble zones are engineering controls. However these and related initiatives can only improve the problem marginally. An innovative and effective way to increase the safety is to eliminate human error, by substituting human error with computer.

Figure 1: Hierarchy of Control (NIOSH 2014).

This is where autonomous vehicles provide an opportunity (Anderson 2014; Ford 2014). It has been predicted that with a 50% share of autonomous vehicles on the road, the number of traffic accidents could be reduced as much as 75% (Fagnant & Kockelman 2013). This also represents a huge economic saving, as will be described in Section 2.1.4: Cost Benefit Analysis. However, it should be noted that human error will still exist in autonomous vehicles, as people will designing and maintaining the system, but it is hoped that AVs should eliminate the crashes due to poor decision making on the road, specially relating to alcohol, fatigue and speeding.

2.1.3 Congestion Improvements

Road congestion in the United States has increased significantly in the past thirty years. Severe congestion can be defined by travel times taking 30% longer than normal. In 1982, only one city in the United States, Los Angeles reached the criteria of 'severe congestion'. However, in 2005, 32 US cities reached this criteria, and it predicted that by 2030, 52 cities will experience 'severe congestion' (Brownell 2013; Staley & Moore 2009). Road congestion in Australia is also a problem, with the average trip taking 27.5% longer than normal in urban areas (TomTom 2015). In addition, research shows that long commutes are negatively associated with physical and mental health (Hoehner et al. 2012).

Autonomous vehicles seek to reduce road congestion by a number of ways. Due to the shorter reaction time of autonomous vehicles, the spacing between cars will be able to made shorter. In addition, due to the interconnectedness of a fleet of AVs, AVs more fluid traffic flow will be able to be achieved (Vine et al. 2015). Also, systems analysis found that more efficient sizing of vehicles (sect. 2.2) and an increase in the rate of ride-sharing (sect. 2.4), would further ease congestion.

2.1.4 Cost Benefit Analysis

While the cost of implementing an SAV network will be undoubtedly be expensive, there are many potential cost savings as shown below. However, the most promising savings occur when there is a large market share of AVs.

Estimated Cost of Implementing an SAV Network

When compared to equivalent ordinary cars, it is predicted that driverless cars will cost between 7,000 USD and 10,000 USD more in 2025, and around 5,000 USD more in 2030 than the equivalent non AV cars (IHS Automotive 2014). Therefore we will estimate the additional cost of an AV to be (5000 ± 2000) USD. It is predicted that an SAV network will be replace approximately 6.5 conventional vehicles (Chen & Kockelman 2015), but will need to be replaced more quickly (every 2 years) due to increased usage (Fagnant & Kockelman 2014). From the number of registered vehicles in Australia of 18 million (ABS 2015) we can calculate the following in Table 2.

Table 2: Cost of implementation of SAV network

Proportion of trips	**Number of AV purchased per year**	**Total Cost per year**
10%	138 000	0.948 ± 0.38 billion AUD
50%	692 000	4.74 ± 1.90 billion AUD

Reduction in number of fatal crashes

In 2013, there were 1187 motor vehicle deaths in Australia (BITRE 2015). Fagnant & Kockelman (2013) estimated that at 10% of trips made by AVs, the crash rate would be reduced by around 5%. This would correspond to a saving of 60 lives. However, if 50% of trips were made by AVs, then the crash rate would is predicted to decrease by 37.5%, resulting in a saving of 445 lives. Comparing multiple sources and converting to Australian dollars, the statistical value of a life was found to be 11.8 ± 0.8 million AUD (US Department of Transportation 2015; Kniesner et al. 2010). Therefore with AVs making 10% of trips the savings would be 710 ± 50 million AUD, and at 50% of trips, the predicted savings would be 5.3 ± 0.4 billion AUD. There are some limitations with this calculation however, since the statistical value of life likely to be different depending on the country.

Reduction in number of hospitalised injury

Over 2012-2013 there were 56,606 hospitalised cases of injury in Australia (AIHW 2015). Taking an extremely conservative estimate, the value of injuries as defined by the US Department of Transportation (2015) is 27,600 USD for the lowest severity of injury, converting to Australian dollars this is 37,800 AUD. Due to differences in health care in Australia and the US, it is estimated that the error is around 5000 AUD. The calculation is followed through below.

Proportion of trips	Crash rate reduction (Fagnant & Kockelman 2013)	Decrease in hospitalisations	Decreased cost (Million AUD)
10%	5%	2,830	110 ± 10
50%	37.5%	21,230	800 ± 11

Reduction in road congestion

A reduction in road congestion would also contribute significant savings, in terms of wasted time, fuel and greenhouse gas emissions. Adjusted for inflation, the time spend travelling in a car can be valued at 13 ± 3 AUD per hour, depending on whether the trip is work or non-work (Douglas et al. 2003). In the US in 2014, 6.9 billion hours were wasted stuck in traffic (Schrank et al. 2015). Since the congestion in Australia is more severe than the US (TomTom 2015), it is reasonable to estimate the total number of hours wasted in traffic in Australia as 504 million hours, by comparing the populations of the two countries. The calculation is followed through in the Table 3.

Table 3: Costs benefit for reduction in road congestion

Proportion of trips	Congestion reduction (Fagnant & Kockelman 2013)	Reduction in travel time (Million hours)	Value of time (Billion AUD)
10%	15%	75.6	0.98 ± 0.23
50%	35%	176.4	2.29 ± 0.53

The summary of the costs and saving is tabulated in Table 4, showing that there is a very significant benefit for a shared autonomous vehicle system in Australia.

Table 4: Summary of Cost Benefit Analysis

	Proportion of trips	
	10%	**50%**
SAV costs per year (billion AUD)	- (0.95 ± 0.38)	- (4.7 ± 1.90)
Savings – time (billion AUD)	+ (0.98 ± 0.23)	+ (2.3 ± 0.53)
Savings – safety (death) (billion AUD)	+ (0.71 ± 0.05)	+ (5.3 ± 0.4)
Savings – safety (injury) (billion AUD)	+ (0.11 ± 0.01)	+ (0.8 ± 0.1)
Net cost benefit (billion AUD)	+ (0.85 ± 0.45)	+ (3.7 ± 2.1)

Therefore at a 10% proportion of trips, the cost benefit is 850 ± 450 Million AUD, and at a 50% proportion of trips the cost benefit is 3.7 ± 2.1 Billion AUD, both of which are a saving. This demonstrates that once autonomous car technology is mature enough, it is a highly effective manner of increasing safety and reducing commuter travel times, and the cost benefit at higher market shares demonstrates that an SAV system will still be viable in the long term.

2.2 Different Sizes of Vehicle in Fleet

2.2.1 Culture of car ownership

Car ownership is clearly part of our culture, and some qualitative and quantitative studies were investigated. While Schoettle & Sivak (2014) found that 61.9% of Australians had an opinion that was either "very positive" or "somewhat positive" towards autonomous vehicles, it was also found that in the UK, US and Australia, more than 50% of people were "very concerned" about riding in a vehicle without controls (Schoettle & Sivak 2014). This demonstrates that while people are interested in the technology of driverless cars, there is a high level of concern about certain situations. Kyriakidis et al. (2014), in a study consisting of 5000 participants, found that the people believed that the most enjoyable part of driving was manual driving.

A survey was also conducted amongst ANU students. Survey questions and coding data are tabulated in Appendix data. A question that the students were asked whether they would prefer to: "own your own self-driving car", or "order one using a phone computer whenever you need it", and it was found that that $(55 \pm 7)\%$ of students would prefer to own their own. The reason that the "self-driving car" terminology was used is because it is more commonly used in mainstream media, while "autonomous vehicle" is more commonly used in the literature. [Note $\pm$ represents one standard deviation, derived from sampling error]. The error is fairly large due to the small sample size (45 people). Thus the main information that can be determined, is that there is no consensus on whether people would prefer to rent or buy autonomous vehicles. There were open ended questions in the survey, and the highest level of attributions against autonomous cars was the enjoyment of driving, confirming the results of Kyriakidis et al. (2014).

This survey has some large limitations. Firstly, the sample is extremely biased and unrepresentative of the broader population, as they are all the participants are university students, with ages less than 25. Secondly, the sample size is too small to determine relationships with a high confidence. To improve this survey, a larger, random sample of the broader community could be taken. However, it was useful to determine some specific qualitative data that was not available in the literature.

KPMG (2013) found that most of their focus group participants would not stop owning a car entirely. However, most would consider giving up their second car, provided a driverless car would be available in 15 minutes. However, many felt owning their own car was an important part of their lifestyle. One participant described their car as a ' "home away from home", filled with his daughter's toys, her car seat, his wife's headshots and costume changes, various phone chargers and other personal effects' (KPMG 2013). Therefore it can be expected that many people will have good reasons why they will not want to give up their car. It would be especially true for families with children. It is speculated that if a family required baby seats then they would not want to rent a driverless car. Successful implementation a shared autonomous vehicles network will almost certainly decrease car ownership (Schoettle & Sivak 2014), but many will not feel like giving up their cars, due to the emotional connection to driving (KPMG 2013).

2.2.2 Recommendations

A possible solution to this problem is to have multiple 'sizes' of driverless cars in the available fleet. This could increase the reach of an autonomous vehicle network. This way a large family could make use of a driverless car network. It also means that if only one or two people need a car, then a 2 person car could be used, providing benefits for fuel efficiency, cost and road space. This hopes to increase the ergonomics and convenience of an SAV fleet.

This solution is likely to increase the reach of autonomous vehicles, but not everyone will be convinced. There always be certain applications where people will need a traditional car, such as car racing, 4-wheel driving, and many people will not give up the enjoyment of driving.

However, there is a middle option, which is to purchase one's own autonomous vehicle outright, which may benefit some people. In fact, the survey conducted among ANU students found that most people would prefer this option. This has still retains some of the advantages of autonomous vehicles, including increased safety, but would be less likely to address the issue of cars only being used 10% of the time (FHWA 2009), and would still have around the same energy and material impacts of conventional automotive. Section 2.4 describes how a shared autonomous vehicle network (especially with ride-sharing implemented) is favourable to a personally owned autonomous vehicle from time, material and energy perspectives.

Therefore it is recommended when a SAV fleet is set up, different sizes of vehicles are available to most accommodate the majority of people's needs.

2.3 Dynamic Relocating

A method to decrease the wait time for potential SAV passengers is to use a relocation algorithm to move unused cars to places of high potential passenger concentration.

2.3.1 Algorithm Operation

A way to reduce the time waiting for a car would be to have a system where a computer program determines the most efficient way to distribute cars to all the population so that the distance that each car must travel is minimised. Figure 2 shows behaviour of traffic volume against the time of day. It is assumed that the amount of traffic volume would be approximately proportional to the demand for driverless cars. This kind of information can be used to predict and model the behaviour of the people waiting in the queue for driverless cars.

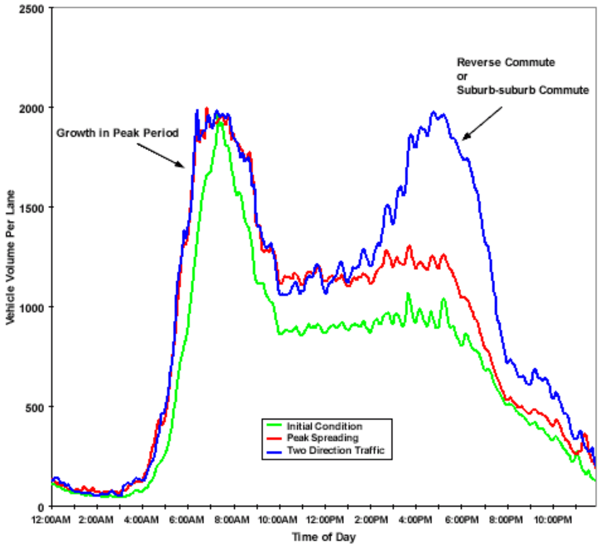

Figure 2: Behaviour over time: traffic volume vs. time of day (FHWA 2013).

A basic relocating strategy is shown in Figure 3, in which the concentration of SAVs is to be disturbed evenly. In Figure 2, the numbers in each cell represent the relative concentration of SAVs in a particular zone, and the arrows show the response of the system, i.e. to move the SAVs into areas of lower SAV concentration (Fagnant & Kockelman 2014). Figure 3 shows the feedback loop for this strategy, which seeks to disperse the vehicles as evenly as possible.

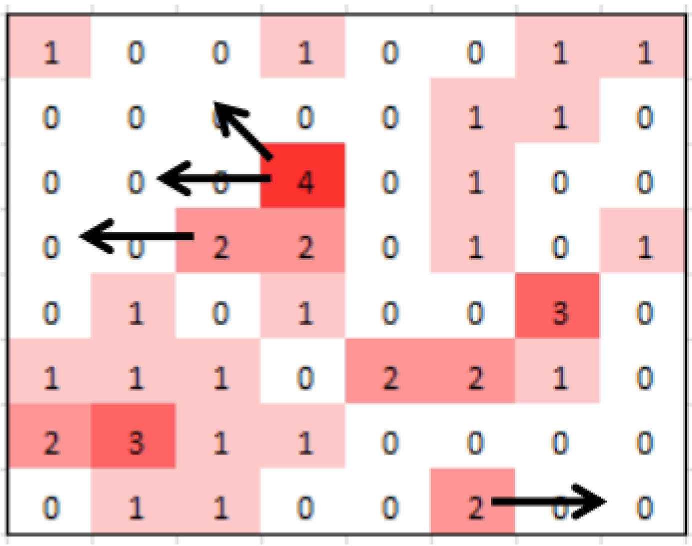

Figure 3: Relocation Strategy (Fagnant & Kockelman 2014).

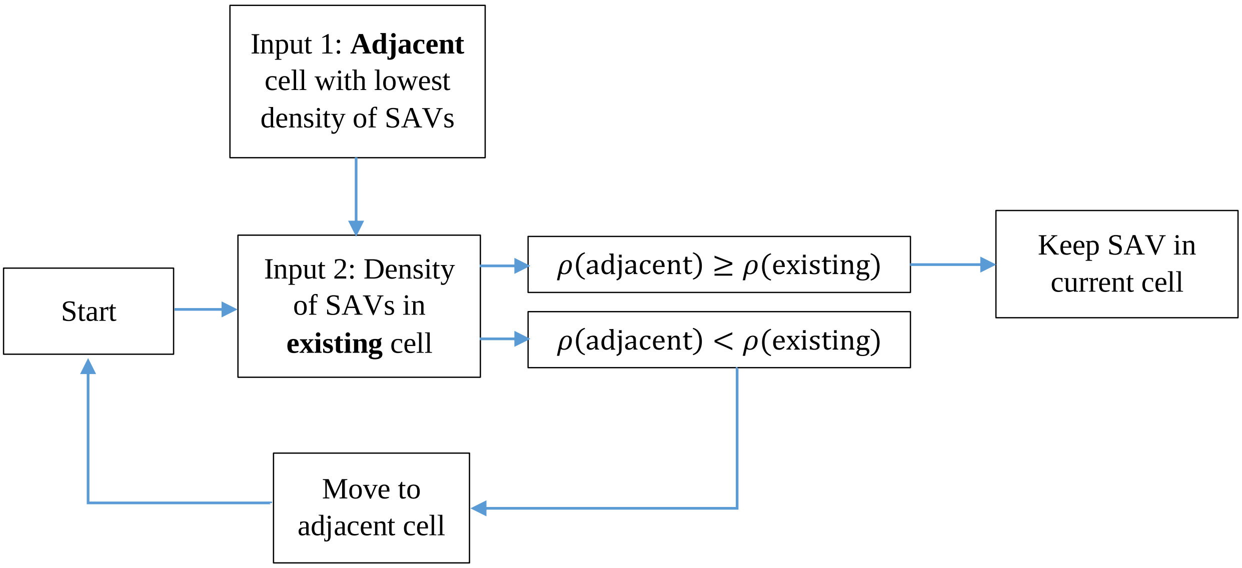

Figure 4: Feedback loop - Dynamic Relocation (Note: $\rho \equiv$ density)

However, the SAV relocating strategy can be further improved by considering where trips are most likely to be started. Information such as Figure 1, can be used to determine this. For example, at the start of the working day, there would be a lot of demand in the outer suburbs for SAVs, but less demand in the city centre. Thus wait time could further be reduced moving more SAVs into areas with higher trip generation rates (Fagnant & Kockelman 2014). It might be the case that at the starting of the working day, there could be an SAV parked right outside of your house ready for you to use, due to a relocation strategy.

2.3.2 Results

Fagnant and Kockelman (2014) found that with no relocation strategy, the average wait time was 42 seconds, but after implementing the relocation strategy, the average wait time was reduced to 20 seconds. Furthermore, less than 0.5 % of passengers waited for longer than 5 minutes. However, a negative of the relocation strategy is the total distance that each SAV travelled increased 5% compared to the base case with no relocation. This is a significant improvement in wait time, so it is recommended that a relocation algorithm is implemented. Note however, that these results were obtained through a computer simulation, over a small service area of 10 miles by 10 mile, with population density to approximate Austin, Texas, so these results may not apply to all areas in which a SAV system is introduced. For example, Chen and Kockelman (2015) found that when extending the surface area to 100 miles by 100 miles, the wait time increased away from the city centre, resulting in a mean waiting time of 3 minutes.

2.4 Grouping Passengers Together Based on Similar Routes

2.4.1 Rationale

Convenience of driverless vehicles is essential to consider when optimising a shared autonomous vehicle network. A way to improve an SAV system is to utilise and encourage ride-sharing. The motivation behind ride sharing is that in Victoria, the average vehicle occupancy rate is just 1.4, with this dropping to 1.14 during morning peak times, so implementing an efficient ride sharing strategy will dramatically decrease congestion and travel time (Stanley et al. 2009). To illustrate the benefit of grouping passengers together based on similar routes we will compare a model where users share a pool of AVs (SAV model) with a model where users have personally owned AVs. SAV system is ideal for a ride-sharing system, since it much easier to manage distribution of vehicles. A ridesharing scheme could possibly work for a system where there are many personally owned AVs, but this would be difficult to manage, since the supply of AVs would not be constant. It would suffer from some of the flaws of Uber, such as unpredictable wait times during demand surges due to short supplies of vehicles, as well as pricing surges (Baydere et al. 2014).

2.4.2 Energy-Mass Balance

An energy-mass balance was conducted to optimise the energy usage within an SAV system, and to demonstrate the grouping passengers together is an effective method of reducing energy requirements within an SAV system.

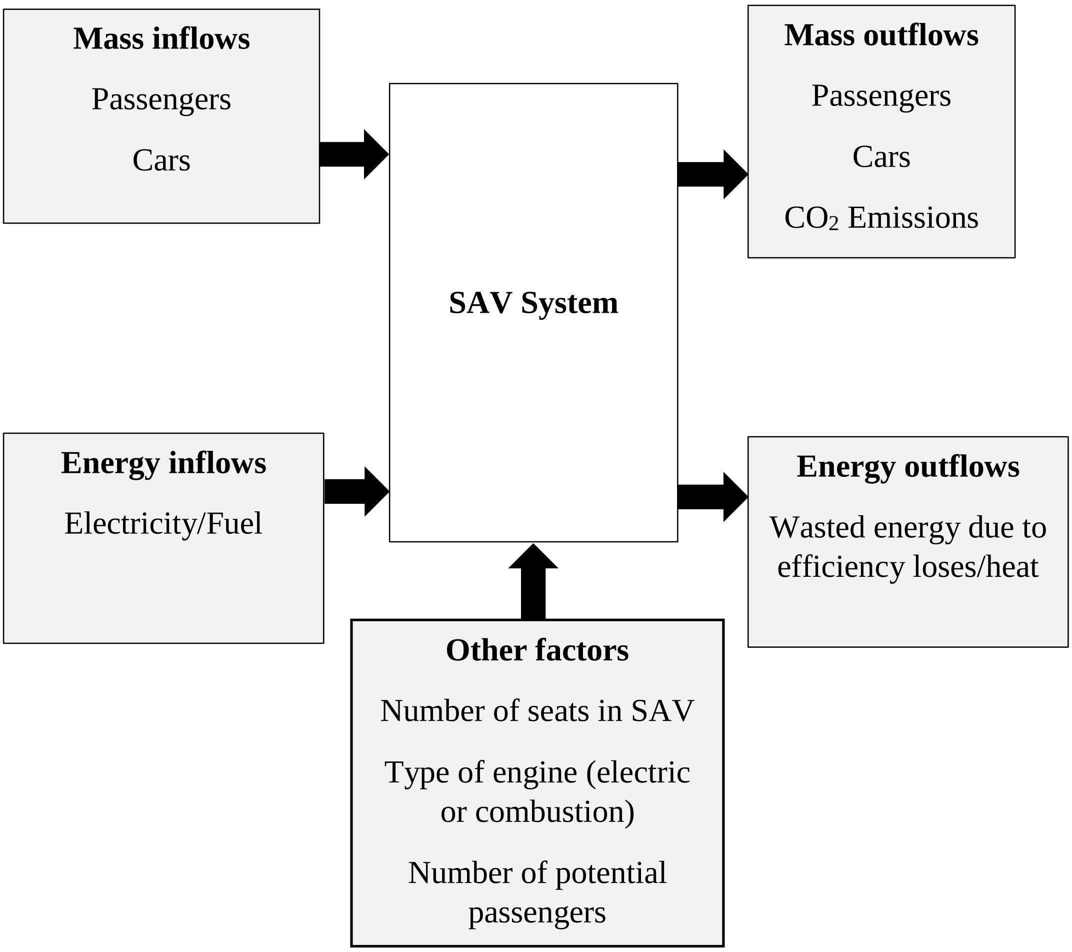

Figure 5: Energy mass balance for SAV system

The mass energy-balance shows that the most significant mass inflows into the system is the number of cars (SAVs). Thus if we can seek to reduce the number of SAVs moving through the system, the energy usage will be reduced. This is due to the total energy usage is roughly proportional to the total distance travelled by all the SAVs, and increasing the number of passengers per SAV will reduce the total distance travelled. Therefore from an energy factors perspective, increasing ride-sharing can be recommended. The energy mass balance also shows that ride-sharing will decrease the number of SAVs required, reducing the total energy impact of the SAV system, as well as cutting the quantity of materials required for manufacturing.

2.4.3 Time Analysis

When comparing the two models of owning and renting owning an AV the time to move through each mode of transport is likely to be different. An adapted PERT/Flowchart chart technique (Figure 6 and Figure 7) was used to show the possible timings of a shared autonomous vehicle network compared with a personally owned AV. For the SAV model, it is possible that if multiple passengers are going to similar destinations, then the car could pick up multiple people to reduce the number of the driverless vehicles required. Figure 6 shows the personally owned AV, while Figure 7 shows the shared model.

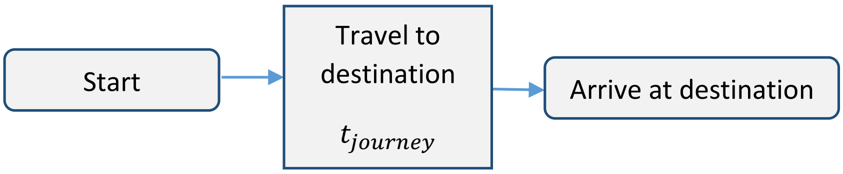

Figure 6: Personally owned AV commute

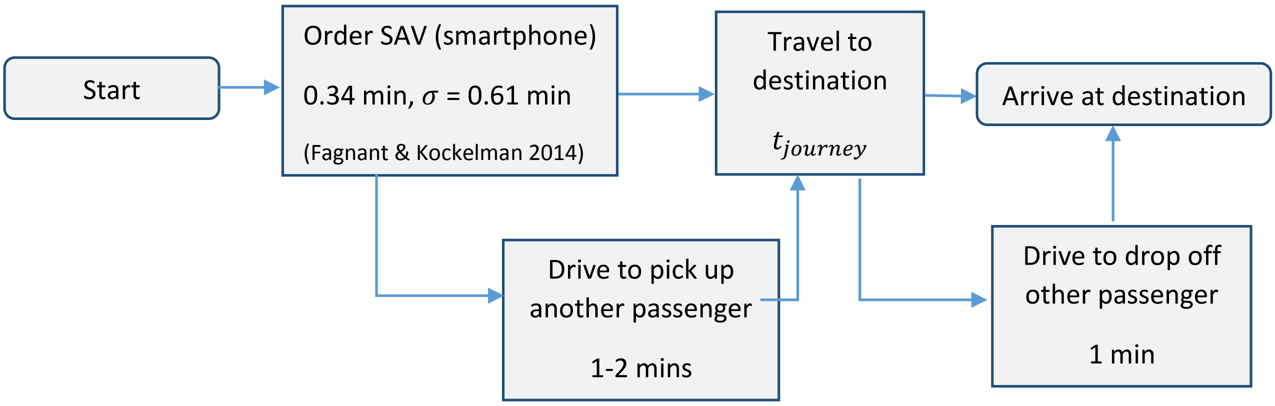

Figure 7: Adapted Flowchart for Shared Autonomous Vehicle Network

Even though the flow chart in Figure 6 for the personally owned non shared AV indicates less steps than in Figure 3, and so the time taken on a journey would be less, in fact by embracing the complete SAV system as is being discussed in this portfolio, this may not actually be the case. If everyone owned their own AV, then there would be more cars on the road, and this would increase congestion, making the total travel time greater than if everyone had used a shared autonomous vehicle system. Thus it will more efficient for everyone if more people use a shared autonomous vehicle system. In order to encourage ride-sharing, service providers of autonomous vehicles may choose to charge a premium for a non-shared journey.

To illustrate this further Figure 8 demonstrates that under a ride-sharing system, the number of vehicles on the road is significantly reduced.

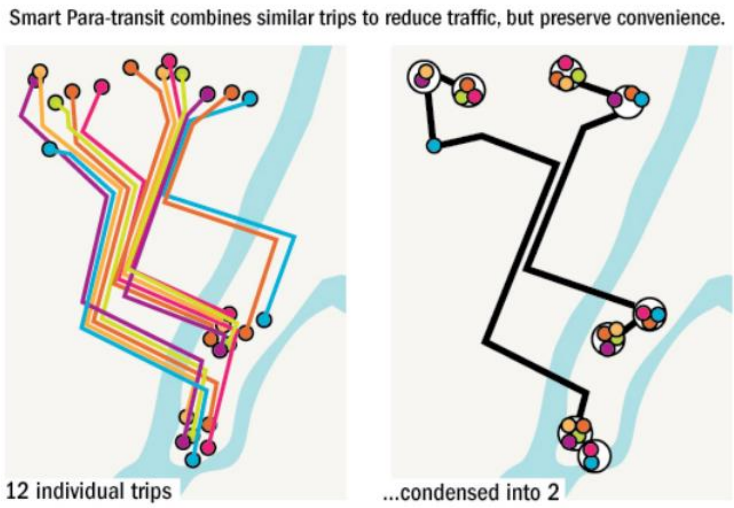

Figure 8: Ride sharing reduces congestion on road (Gorton 2008).

2.4.4 Recommendations

It is recommended that an efficient method to allow ridesharing be implemented in an SAV network, with passengers receiving discounts for sharing the vehicle with others taking similar journeys. This will reduce the commuting time for passengers, the energy usage and the material impact of the SAV network.

3 CONCLUSION

Clearly, there will be many challenges as society moves into a new era of autonomous vehicles, and a systems engineering methodology will be an effective means of organising discipline specific research. It was shown that an SAV network would have a reduced environmental impact in comparison to a traditional automobile system, as well has having increased safety, as evidenced by the hierarchy of controls. A cost analysis was conducted, showing that despite the extra purchase price of SAV vehicles, there would be cost saving across safety and congestion far outweighing the additional capital. Analysis of qualitative data in relation to ergonomics found offering different types of vehicle was an effective means of increasing uptake. It was recommended that a dynamic relocating method is implemented to decrease passenger wait time, and through an energy-mass balance and time analysis it was recommended to group passengers together based on similar routes. Autonomous vehicles have the potential to transform society, and they may come sooner than we think!

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Appendix A: Survey Questions

All information collected is anonymous. This information is being sought for a portfolio entitled "Driverless Cars: Rent or Buy?". The purpose of this survey is to gather information on user perceptions of driverless cars.

The student is Oliver Johnson, email: u5570104@anu.edu.au. The information you provide will only be used for the purpose of this portfolio. There is no obligation to complete the survey if you do not wish.

1. What is your age?
   - ○ Under 18
   - ○ 18-24
   - ○ 35-34
   - ○ 35-44
   - ○ 45-54
   - ○ 55-64
   - ○ 65+
2. How often do you drive per week?
   - ○ Every day
   - ○ 2-3 times per week
   - ○ Once per week
   - ○ Less than once per week
3. Do you own your own car?
   - ○ Yes
   - ○ No
4. If they were available, how likely would you be to use a self-driving car?
   - ○ Extremely likely
   - ○ Very likely
   - ○ Moderately likely
   - ○ Slightly likely
   - ○ Not at all likely
5. Please help us understand why you selected the answer above:

6. Would you prefer to:
   - ○ Own your own self driving car

- ○ Order one on a phone or computer whenever you need it

7. Please help us understand why you selected the answer above: