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Learning from the autonomous experience

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Abstract

As an emerging transport technology, autonomous vehicles present a potential to better cater for travellers' needs. The Flinders Express (FLEX) autonomous shuttle bus trial in metropolitan Adelaide has provided an opportunity to gain insights and an understanding on issues associated with autonomous transport services. Surveys of FLEX passengers before and after a trip on the service has resulted in a powerful database to enable an assessment of changes in opinion, grounded in first-hand experience. This paper presents a selection of these findings, with the results underscoring how a real-world experience can influence opinions about a range of autonomous vehicle aspects.

1. Introduction and context

Autonomous vehicle technology is becoming ever more present on roads in a wide range of forms, with 'driver assist' features to complete 'hands-off' driving operations. Levels of vehicle automation as defined by the Society of Automotive Engineers range from level zero (driver warnings) to level 5 (fully driverless in all conditions) with in-between levels identifying features such as parking assistance, adaptive cruise control and partial automation under certain conditions (SAE, 2018). To suit Public Transport (PT) operations The International Association of Public Transport defines another five grades of automation (UITP, 2012) identifying an increasing level vehicle automation with additional functions recognised such as door opening for passenger alighting or departing and connecting with centrally operated system controls. Such emerging technologies can provide many opportunities for PT operators but also challenges, which may vary according to passenger type, operational setting, expectations and perceptions.

Advances in Autonomous Public Transport (APT) technology has allowed for operational trials in cities such as Singapore, Vancouver (Canada), Michigan (USA) and Lyon (France) (Pakusch and Bossauer, 2017). Vehicle manufacturers such as Navya, Local Motors, Easy Mile and Aurrigo all have commercially available models on the international market suitable for APT service. Indeed, many trials internationally are currently testing vehicle functionality and capability under a wide range of service conditions. Locations such as airports, retirement villages, university campuses and tourist locations in both urban and regional settings are trialling APT services that in many cases integrate with existing PT operations and activity centres. Such integration has the potential to overcome 'traditional' challenges faced by PT operations, especially in the context of low population densities and strong competition from alternative modes (Hensher, 2000). Advantages of APT can include a lower error and accident rate, greater availability through reduced dwell times and shorter headways, increased punctuality and potentially reduced passenger transport costs (Pakusch and Bossauer, 2017). In addition, the is a potential for offering a higher frequency of service in off-peak periods, provided the operating costs are lower than a conventional bus with higher flexibility in adapting the supply to demand due to the lack of drivers' scheduling constraints (Alessandrinia et al, 2014).

For much of the community, the current perception towards APT and autonomous vehicles generally stem from the level of personal trust placed in the technology and operation. To ensure success, people will need to trust both the operational safety offered by AVs and trust how, when and why journey data might be used (IPA, 2017). Trust also extends to the sense of security experienced by passenger as Salonen (2016) reports on AV passengers experiencing a lack in the sense of on-board security, even when not alone. Other challenges for this mode relate to infrastructure needs, legal and ethical considerations, privacy, short-term economic considerations. Benefits to the passenger relate to enhanced mobility and direct transport costs with the potential to impact the value individuals place on travel time itself. Benefits extend to other road users, for example they empower pedestrians and cyclists because autonomous vehicles are more sensitive to other road users than human-driven vehicles (Millard-Ball, 2016).

2. The Flinders Express trial

The Flinders Express (FLEX) trial is based at the Tonsley Innovation district, a mixed land use precinct containing a university campus, residential housing and a range of small businesses over 55 hectares located in metropolitan Adelaide, Australia. The trial itself involves a Navya Autonom vehicle as a first and last-mile APT operational context, connecting an adjacent rail station to the precinct as it travels around a 2.2km circuit with 4 stop locations as depicted in Figure 1.

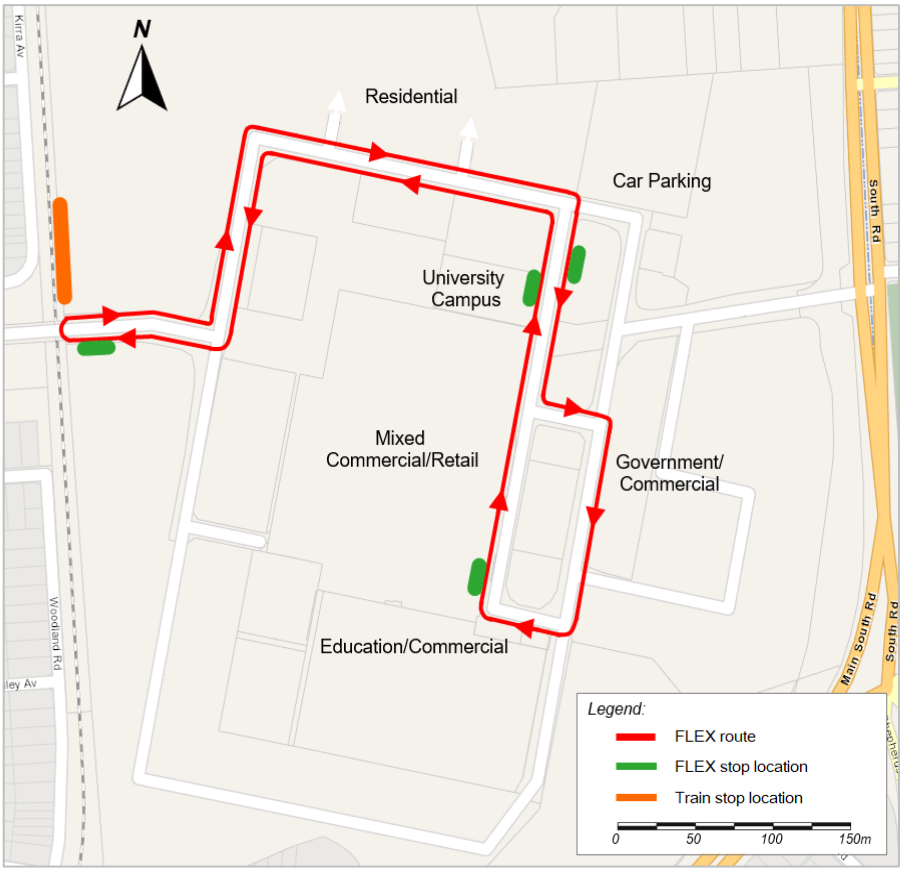

Figure 1: FLEX route including stop locations.

The FLEX Navya vehicle is equipped with technology such as LIDAR scanners, Global Positioning System (GPS) antenna, inertial measurement units (IMU's), on-board cameras and cellular network communications (Figure 2). With the use of these systems, the vehicle can safely navigate the route as it positions itself on the road whilst travels whilst generating a sense of the real-time operational environment.

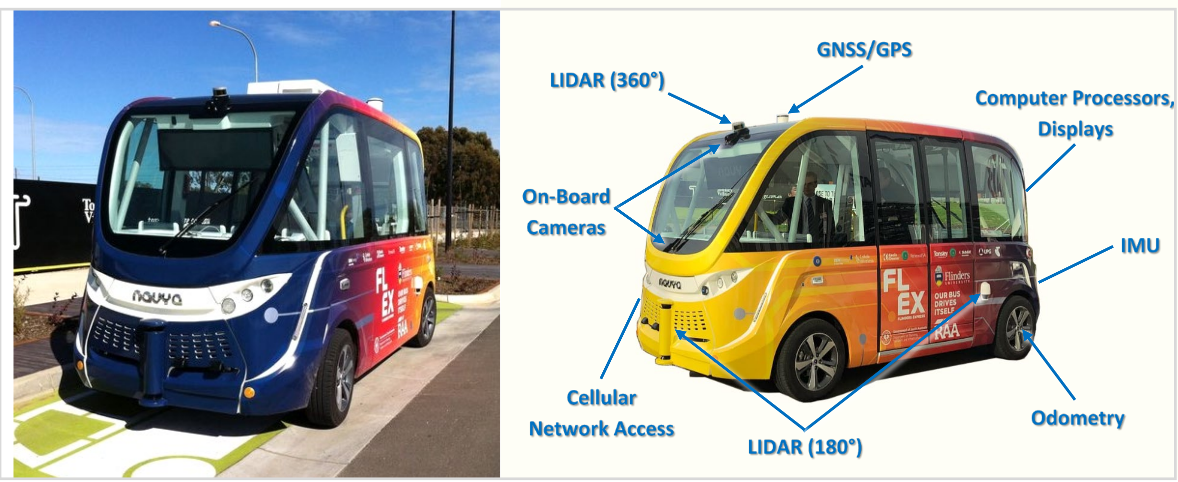

Figure 2: FLEX Navya Autonom at a stop location and vehicle technologies.

Passenger travel on the FLEX service can be achieved by either booking ahead or simply boarding the bus at one of the stop locations. The FLEX service operates on weekdays between 10:00am and 2:00pm travelling at a maximum speed of 20km/hr and completing the circuit route in approximately 15 minutes.

3. FLEX survey design and deployment

During the online booking process, passengers are asked to respond to an online survey questionnaire, with the aim of gaining an understanding on a range of topics associated with APT services before riding on FLEX. These passengers are sent a follow-up email after their trip, requesting that they complete the online, after-ride survey. The surveys generate anonymous responses that are not matched in pairs, allowing for broad comparisons between response cohorts. This approach does not however allow for direct pairwise comparisons.

This form of before-and-after survey is powerful in that it enables an assessment of changes in opinion, grounded in first-hand experience. Respondents are initially asked about personal attributes such as age, gender, home address postcode as well as their general AV knowledge and experience. Continuing from this are a series of questions established as a series of Likert-style questions (Likert, 1932) in order to rank responses using a 5-point scale. These relate to levels of agreement, concern and positive or negative feeling towards aspects of AV's. Ranking questions are applied to the following classifications:

- General knowledge and experience,
- Safety and security (eg. accidents and data privacy),
- Traffic efficiency (eg. travel time reliability and congestion),
- Costs (eg. out of pocket transport costs),
- Mobility and interaction (eg. independence and on-road interactions) and
- Use and other implications (eg. learning to use new technologies and social impacts).

Other more general commentary is welcomed in the form of open-ended questions at the end. Each of the before and after surveys take around 5-10 minutes to complete and were conducted over a 9-month period during the trial.

3.1 Survey response

FLEX surveys provided a total of 575 valid responses that have been used in analysis, encompassing both before and after FLEX ride response types. Sample sizes for the before FLEX and after FLEX ride response cohorts are n=383 and n=192 respectively. The survey dataset only contains responses from adults aged 18 years of older with a gender of 55% female to 45% male before and 58% female to 42% male after. The majority of combined responses respondents are middle-aged, representing the 35 to 44 age cohort as illustrated in Figure 3.

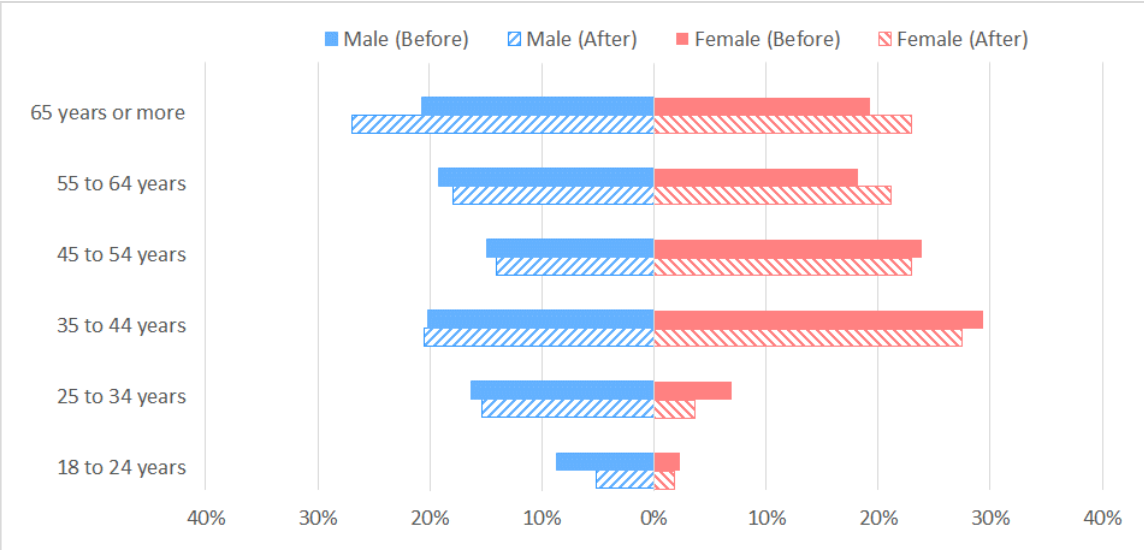

Figure 3: Age and gender split of survey respondents.

Comparing the before and after response proportions in Figure 3, both male and female show a tendency to skew towards older age groups in the after-FLEX ride responses. This shift is most prominent among males aged 65 and above and females aged 55 and above. Consequently, there's a decline in the proportion of younger respondents. This obseravtion on differences in overall sample sizes and age distribution holds importance in result interpretation as it presents a potential for bias in the response groups.

With education facilities including the Tonsley campuses for TAFE and Flinders University located on-site, a high proportion (14%) of passengers report as students, although respondents were not asked to report on trip purpose. From the reported postcode, the vast majority (94%) reside in metropolitan Adelaide with many (53%) locals, residing within an 8km radius of the Tonsley site. Very few report to live in regional Australia (3%) or come from interstate/overseas (3%), thus the dataset can be viewed as largely representative of a local, metropolitan Adelaide cohort.

Analysis and comparison of responses both before and after riding on FLEX is performed with the objective of establishing if the driverless vehicle experience has an influence on personal perspectives and attitudes. Beyond this objective the investigation also explores what this likely means for not only the FLEX trail but also the development of autonomous vehicles policies. Reporting occurs on Likert ranking means and standard deviation as an indication of the average response as well as the degree of variation within the response cohort. The application of an independent sample t-test allows for hypothesis testing (Ugoni and Walker, 1995) involving a comparison of before and after data, to demonstrate where a statistically significant change occurs in opinions.

3.2 General knowledge and awareness

Awareness and general knowledge relating to autonomous vehicles responses are depicted graphically in Figure 4, representing the sample of 383 before FLEX ride responses. The overwhelming majority (94%) of people report to heard of the concept of an autonomous vehicle however only 39% report to know what an autonomous vehicle is. Respondents may be aware of terminology and perhaps the principle of a no-driver vehicle but unsure about a specific definition. Here, 28% reported unsure/need more information to define the term, which may be a result of the unspecific nature of this question. Few people (12%) report to have actually had an in-vehicle autonomous experience before the FLEX ride. As the survey does not define autonomy or autonomous vehicle features, this experience could include any of the 5-levels of autonomy ranging from driver assistance features (such as adaptive cruise control or parking assist) to fully driverless.

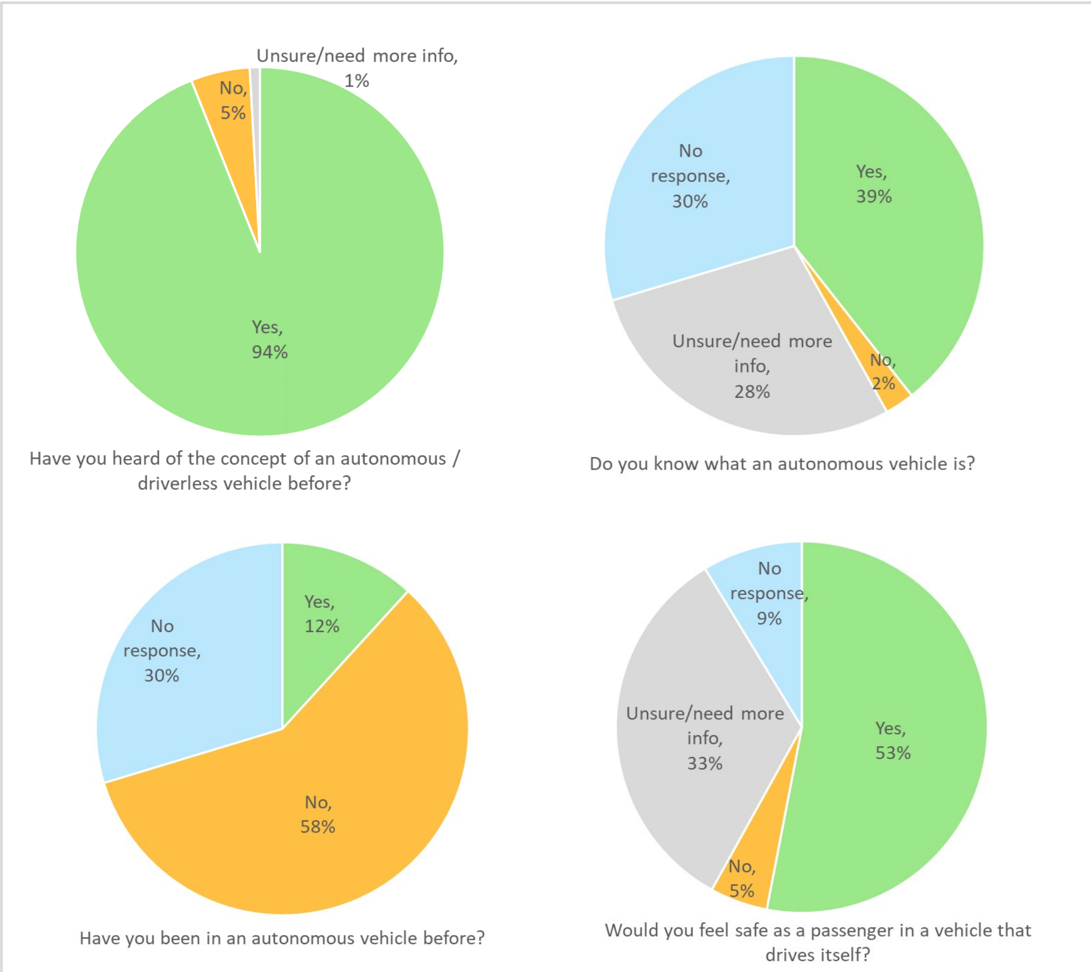

Figure 4: General knowledge and awareness relating to autonomous vehicles.

4. Before and after FLEX ride comparisons

Survey respondents are asked to rank their level of agreement with proposed statements between 1 and 5 as representations of their opinion such as “1” is strongly disagree, “2” is disagree, “3 is neutral, “4” is agree and “5” is strongly agree. From this ranking it is possible to establish that a mean score greater than 3 indicates a general preference towards agreement with the proposition and conversely a mean of less than 3 represents disagreement. Standard deviation of the mean will provide an indication of the variation within the response set and with the levels of agreement/disagreement with the proposition statement.

Comparison between before and after FLEX ride survey datasets are possible with the application of the t-test to derived sample set means. Changes to the mean ranking value may be observed between the before and after responses and along with the direction of that change, i.e. towards agreement or towards disagreement. The t-test provides the ability to see if that change is statistically significant. Changes in the standard deviation are also of interest as this can indicate if the survey responses show more or less variation in responses.

The purpose of this testing is to investigate the hypothesis of a significant difference between the mean of the "before" sample (μ_{before}) and the mean of the "after" sample (μ_{after}) or in other words if the FLEX experience has induced a significant change in opinion. If the null hypothesis is accepted, we have H_0; $\mu_{before} = \mu_{after}$ (i.e. there is no significant change in the mean values from before to after or the FLEX ride has not induced a change in the ranking means) and as an alternative H_1; $\mu_{before} \neq \mu_{after}$ (i.e. a significant change is observed). The $t_{statistic}$ is reported with associated p value wherein if our calculated $t_{statistic}$ is > $t_{critical}$ this indicates a rejection of the null hypothesis, as there is a greater than 95% chance that the alternative hypothesis H_1 holds true and there is a significant difference between means. In support, if the resulting $p < 0.05$ the same result can be deduced. For a two-tailed t-test, the $t_{critical}$ is estimated to be 1.968 response samples as unpaired and unequal in size. Responses are treated as scalar values with normal distributions and comparable variance and as such suitable to be analysed with parametric statistical testing.

Responses to Likert surveys are summarised in Table 1 with both before and after estimates of mean and standard deviation values along with t-statistic and p-value. These responses relate to the question: ***To what extent do you agree or disagree that the following statements would occur if all vehicles on our roads were driverless?*** Individual propositions are shown in the first column.

	Before FLEX Ride		**After FLEX Ride**			
Autonomous vehicles would result in…	**Mean**	**StdDev**	**Mean**	**StdDev**	**t-statistic**	**p-value**
fewer crashes.	3.737	0.894	3.802	0.948	0.815	0.415
reduced severity of crashes.	3.778	0.908	3.927	0.921	1.895	0.059
less traffic congestion.	3.623	0.953	3.625	1.049	0.021	0.984
improved travel time reliability (more consistent journey times).	3.768	0.892	3.760	1.003	0.093	0.926
less need for public parking in towns and cities.	4.093	0.926	4.125	0.859	0.425	0.671
lower insurance rates.	3.590	0.962	3.609	0.979	0.232	0.817
better fuel efficiency.	3.896	0.880	4.063	0.827	2.307	0.022
enhanced freedom and independence for the young, aging and those with mobility difficulties.	4.172	0.920	4.354	0.818	2.518	0.012

your travel time being used more effectively / productively doing other activities.	4.037	0.869	4.021	0.941	0.209	0.835

Table 1: Summary of before and after FLEX ride ranking statistics.

4.1 Crashes and crash severity

The development of a safe operating environment for autonomous vehicles is a concern to all stakeholders in this field including transport operators, legislators, passengers and the broader community, making it very much an interdisciplinary challenge (Koopman, 2016). Successful deployment of driverless vehicle transport networks has the potential to offer vast safety benefits, however public acceptance must deal with current community concerns related to vehicle or system failures, legal liability and differences such as using a vehicle with no driver controls (Commonwealth of Australia, 2017).

In response to the proposition that autonomous vehicles would result in fewer crashes, the mean ranking result increases in value between the before FLEX and after FLEX response sets from 3.737 to 3.802, indicating a high initial level of agreement, increasing slightly after a FLEX ride experience. The $t_{statistic}$ does not exceed the $t_{critical}$ value of 1.968 which means that the null hypotheses must be accepted as no significant change in the mean or very little change in opinion before and after the FLEX experience. A small increase is observed in the standard deviation, indicating only a very small broadening of opinions here. For the proposition that autonomous vehicles would result in reduced severity of crashes, again an increase in the value of the mean is observed and although $t_{statistic} < t_{critical}$, it is 1.895 and so close to this threshold. It would be reasonable to state that there is a close to significant change in opinion that of people believing that autonomous vehicles would result in reduced crash severity after taking a FLEX ride.

Although the FLEX ride didn't change people's opinion in relation to fewer crashes, this had initially high general agreement, although the neutral position was prominent with 30% remained "neutral" after. More change was in opinion observed in relation to crash severity, which may be attributed to the low speed of FLEX vehicle and operational environment as a local road network and relatively low traffic interaction.

4.2 Congestion, reliability and parking

The efficient operation of transport networks is important for urban regions with traffic congestion and inefficient travel leading to unreliable networks (Lym and and Robert, 2008), as well as impacting negatively on the environmental, social, safety, health and economic aspects of travel (Weisbrod et al 2001, Wang et al, 2009, Beelen 2008 and BITRE 2006). Transport efficiency is investigated in the survey by gaining perspectives on a selection of transport efficiency indicators and the role of autonomous vehicles. This component of the survey addressed issues around the perceived impact of driverless vehicles on traffic congestion, travel time reliability and the need for parking provisions in urban areas. For all cases, both before and after mean responses tend toward agreement that driverless vehicles would have a positive impact in these areas.

When asked if autonomous vehicles would result in less traffic congestion, there was very little change in the mean from before to after responses as $t_{statistic}$ of 0.021, far lower that the $t_{critical}$ value of 1.968. The SD of the mean response is relatively large at 1.049, indicating one of the largest variances in responses to this issue with many differing opinions gained. Improved travel time reliability (more consistent journey times) gained a very similar result to the previous outcomes in terms of mean and standard deviation. This may not be surprising give the perceived close relationship between traffic congestion and travel time reliability. When compared to the previous two observations, the results for the *less need for public parking in towns and cities gained* greater t-statistic in magnitude, however still indicates a low degree of change in opinion. The after-FLEX ride mean values overall were quite high at 4.125 after the FLEX ride, indicating quite strong overall level of agreement with the proposition that there may be less need for public parking if all vehicles on our roads were driverless. In addition, a lower after-FLEX standard deviation indicates less variance in this response and a stronger overall level of agreement across all responses.

Respondents may be unsure about or doubtful of the relationship between autonomous technologies and traffic efficiency factors. A direct connection may not be obvious and so lead to relatively lower means as representations of agreement compared with parking, which has a higher mean value. In this case, FLEX presents itself as an APT mode and therefore reduces the need for car travel and parking. In all cases, a FLEX ride does little to change opinion.

4.3 Insurance and efficiency

A significant influence on individual transport behaviour is the personal financial costs associated with achieving the travel task (Steg, 2003, Vlek and Michon, 1992 and Gargett and Hossain, 2008). Such costs can be incurred frequently and on a regular basis (such as petrol purchases or toll charges) and influenced by factors such as petrol price, fuel efficiency Infrequent costs include such items as insurance premiums or vehicle maintenance. Two general aspects that impact on costs are insurance and daily vehicle running costs, both of which are explored in the survey.

Respondents reported the lowest mean values of all questions in relation to autonomous vehicles resulting in lower insurance rates. An after-FLEX ride mean-value of 3.609 was achieved, still indicating more agreement than disagreement however the after-ride results had an insignificant change in the mean value compared to before as the as $t_{statistic}$ of 0.232 does not exceed the $t_{critical}$ value of 1.968.

In response to the better fuel efficiency proposition, a comparison/evaluation of the mean responses before and after the FLEX ride reveals a $t_{statistic}$ of 2.307 (> $t_{critical}$ value of 1.968) indicating a significant change in mean responses. Observations also show a movement towards a greater mean value of 4.063 after the FLEX ride that indicating a strong overall level of agreement with the proposition that the use of driverless vehicles would result in better fuel efficiency. From Table 1 a reduction in standard deviation can also be observed indicating less variance in response after the ride as the ride has allowed people to be more certain of their response.

A high level of agreement with the statement on fuel efficiency may be related to two factors, firstly the autonomous vehicle is electrically powered (as many are) and it also is a low-speed public transport service. The connection between insurance and autonomous vehicles may not present itself to respondents and results in a much lower level of agreement.

4.4 Independence and productive use of time

Analysis of issues associated with personal independence and the travel time being used more effectively are considered in this section. Independence can be associated with ethical issues which have a strong association with autonomous vehicle use as outlined by Lin, (2016) and "an ethical response to the fully autonomous driverless cars is developed by addressing autonomy, community, transparency, identity, value and empathy" (McBride, 2016). The *enhanced freedom and independence for the young, aging and those with mobility difficulties* statement achieved the overall highest mean Likert response from all surveyed ranking responses with the greatest mean value shift, towards a value of 4.354. This is reflected in the $t_{statistic}$ result at 2.518 indicating greatest impact and most statistically significant indication of the FLEX ride experience on personal opinion change towards a greater level of agreement with the statement. The high mean response value is an indication of with agreement as this statement received 52 % of 'strongly agree' responses after the FLEX ride.

Your travel time being used more effectively / productively doing other activities also resulted in very high mean of Likert ranking of 4.021 after the FLEX ride. This compares with a before FLEX mean of 4.037, resulting in a low $t_{statistic}$ of 0.209, indicating an insignificant shift in the mean. Slightly more general disagreement with his statement… preoccupied with the interaction rather than other productive tasks.

A very high level of agreement has been achieved with both statements relating to personal independence and productive use of time. The FLEX ride has had a very positive impact on riders in this context, even with initially high levels of agreement before the on-board experience. In these areas it is possible to deduce the public perception for autonomous vehicles potential to enhance mobility and quality of travel time.

5. Discussion

In general, the survey population report on their awareness of autonomous vehicles. Although few report to have had experience with autonomous, they are more likely to be aware of driverless features such as adaptive cruise control and other driver assist features. Responses gained from the questionnaire indicate the greatest level of agreement on autonomous vehicles providing *enhanced freedom and independence for the young, aging and those with mobility difficulties* and *less need for public parking in towns and cities.* The greatest disagreement occurs with autonomous vehicles providing *lower insurance rates* and *less traffic congestion*.

When comparing before and after FLEX ride responses the greatest shift in opinion occurs for *enhanced freedom and independence for the young, aging and those with mobility difficulties.* Overall, many responses saw a reduction in a "3" ranking on the Likert scale representing neutral-stance responses. A "3" response may indicate no feeling either way (towards agreement or concern) which could be driven by factors such as limited knowledge or indifference. In cases where the ranking question is repeated after a ride on FLEX, the amount of neutral responses were reduced. This result emphasises the significance of a real-life experience to change opinion on a range of autonomous vehicle aspects. The FLEX trial has allowed the general public to develop their knowledge and understanding of autonomous applications and helped to them to foster an opinion where one may not have been present before. Survey outcomes will help the professional transport planning community to identify important aspects of autonomous vehicle operations, especially in relation to public opinion, education as well as policy and planning implications.

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