Intelligent Transportation Engineering: What is Needed?

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ABSTRACT

There has in recent times been rapidly growing interest in innovative technologies to improve transportation systems, including advanced traffic management technology for real-time traffic management, and advanced vehicle technology (i.e. autonomous vehicles) to improve traffic safety.

The use of innovative technology has been promoted by technology suppliers (e.g. vehicle manufacturers) and advocacy groups (e.g. the Intelligent Transportation Society of America), with claims of very large benefits. However, there have in the past been quite a few instances of innovative technologies, widely heralded as solutions to transportation problems, failing to fulfil the claims of their promoters or having unexpected and unintended adverse effects.

This paper will argue that intelligent transportation engineering involves much more than simply adopting the latest technological innovations. It requires one to clearly identify objectives, then to identify options with high potential for achieving the objectives, then to appraise those options thoroughly (including anticipating future problems), then to select and implement the best option, and finally to recognise uncertainty in estimates of the impacts of options (including the potential for 'optimism bias') and to evaluate the implemented option thoroughly, to facilitate evidence-based decisions in the future.

This paper will review recent research on the effects of autonomous vehicles (private and shared) on road network capacity, urban form, travel behaviour and traffic safety. It will also discuss legal liability issues (civil and criminal) and ethical issues.

This paper will argue that intelligent transportation engineering requires a more discerning approach, recognising the hype and vested interests associated with some options, the importance of basing decisions on evidence rather than ideology, and the scope for achieving objectives via good existing low-technology options. It will be argued that transportation engineers should be active in setting objectives and specifying what is needed to achieve them, and not just passive recipients of innovative technology.

INTRODUCTION

Currently, there is rapidly growing interest in innovative technologies to improve our transportation systems, including:

- advanced traffic management technology (e.g. real-time traffic management);
- advanced vehicle technology (e.g. autonomous vehicles).

These technologies are being promoted by technology suppliers and advocacy groups (e.g. the Intelligent Transportation Society of America, established in 1991 with the goal “to save lives, time and money and sustain the environment, through broad deployment of interoperable ITS technologies”).

The reputation of engineers as good ‘problem solvers’ is based largely on their ability to solve existing problems, which are generally well-recognised and well-defined. Solving these can require considerable intelligence, but greater intelligence is needed to solve existing problems without creating other problems. For instance, in the late 1800s, an existing problem in large cities all around the world was horse manure. London had over 50,000 horses for people transport (excluding horse-drawn goods transport) and New York had about 100,000 horses for transport. Each horse produced 7-16 kg of manure and about one litre of urine per day, and it was estimated that in 50 years horse manure on London streets would be about 2.75 m deep. The automobile was seen as solving that problem.

However, horse manure was not the only problem. In the late 1870’s (i.e. pre-automobiles), about 240 people were killed and about 3200 injured each year on London streets (Hobbs, 1974). The population of London at that time was about 4.5 million, so there were about 53 deaths per million inhabitants. In 2010-2014, there were about 1800 road deaths/year in the whole of the UK (Department for Transport, 2016a). With the UK population being about 65 million in 2012, there were about 28 deaths per million inhabitants.

While safety has improved since the introduction of automobiles, the elimination of horse manure on roads has resulted in greatly increased greenhouse gas emissions.

Intelligent transportation engineering involves much more than simply adopting the latest technology. It involves the following steps:

- clearly identify the objective;
- identify the options with a good level of potential for achieving the objective;
- appraise those options thoroughly (including anticipating future problems);
- select and implement the best option;
- recognise the uncertainty and potential for ‘optimism bias’ in appraisal, and evaluate the implemented option.

The NZ Transport Strategy (Ministry of Transport, 2008) specified a vision (“an affordable, integrated, safe, responsive and sustainable transport system for people and freight”) and five key objectives:

- ensuring environmental sustainability;
- assisting economic development;
- assisting safety and personal security;
- improving access and mobility;
- protecting and promoting public health.

The UK had five very similar objectives (Department for Transport, 2009).

A recent report (Ministry for the Environment & Statistics NZ, 2017) notes that the two largest sources of greenhouse gas (GHG) emissions in NZ in 2015 were the digestion of animals and road transport, with about 28.1 Mt and 13.3 Mt of CO_2-e per year, respectively. However, the growth in transport emissions (78% since 1990, or about 5.20% per year) is very much larger than the growth in animal digestion emissions (5% since 1990, or about 0.33% per year). If these growth trends continue, road transport emissions will exceed animal digestion emissions in about 24 years. Clearly, the sustainability of transport, especially road transport, which accounted for 90% of domestic transport GHG emissions in 2015 (Ministry for the Environment, 2017), is a problem that urgently needs to be addressed in NZ.

After about 10 years of fairly steady improvement in road safety, there has been a fairly steady deterioration, with distinct upward trends in both deaths and injuries associated with road crashes, since the end of 2014 (Ministry of Transport, 2017), and road safety remains a problem which also needs addressing in NZ.

In recent years, there has been a strong focus on autonomous vehicles (AVs) as the solution to existing transport problems, particularly those related to safety and sustainability. This paper will review recent research on the effects of AVs (private and shared) on safety and sustainability. It will also review recent research on the effects of AVs on road network performance, urban form and travel behaviour, and will discuss legal liability issues (civil and criminal) and ethical issues.

AUTOMATION OF DRIVING TASKS

Levels of Automation

The Society of Automotive Engineers (SAE) defined three types of driving tasks (Society of Automotive Engineers, 2014):

- operational (steering, braking, accelerating, monitoring vehicle and roadway);
- tactical (responding to events, determining when to change lanes, turn, use signals, etc.);
- strategic (determining destinations and waypoints).

The first two tasks constitute the dynamic driving task (DDT), and this has been the focus of automation efforts to date.

The SAE also defined ‘driving mode’ to mean a driving scenario with characteristic DDT requirements (e.g. expressway merging, high speed cruising, low speed traffic jam, etc.), and a request to intervene (RTI) as a notification by the automated driving system (ADS) to the human driver/supervisor to promptly begin or resume performance of the DDT.

The SAE has defined six levels of automation:

- Level 0 (no automation): driver performs 100% of DDT full-time (with warning or intervention systems);
- Level 1 (driver assistance): driver monitors and ADS assists driver with other tasks for some modes;
- Level 2 (partial automation): driver monitors, ADS performs other tasks for some modes.
- Level 3 (conditional automation): ADS performs 100% of DDT part-time for some modes;
- Level 4 (high automation): ADS performs 100% of DDT full-time for some modes;
- Level 5 (full automation): ADS performs 100% of DDT full-time for all modes.

Note that if the ADS is unable to cope and it makes an RTI to the driver/supervisor, this might mean that legal liability for a crash shifts from the vehicle/ADS supplier to the driver/supervisor. This issue is discussed later.

The UK has adopted a four-level system (Department for Transport, 2016b):

- Level I (No automation)
- Level II (Driver assistance)
- Level III (Partial → High automation)
- Level IV (Full automation)

Note that SAE levels 2 – 4 have been merged into one level (Level III).

Technology Readiness Assessment

There are several stages in the development of any technology, and the maturity of technology can be assessed using nine 'technology readiness' levels (Department of Defense, 2011):

1. basic principles observed and reported;
2. technology concept and/or application formulated;
3. analytical and experimental critical function and/or characteristic proof of concept;
4. component and/or breadboard[1] validation in laboratory environment;
5. component and/or breadboard validation in relevant environment;
6. system/subsystem model or prototype demonstration in a relevant environment;
7. system prototype demonstration in an operational environment;
8. actual system completed and qualified through test and demonstration;
9. actual system proven through successful mission operations.

It would appear that AV technology readiness is no further than the early stages of the sixth level.

These 'technology readiness' levels are very technical in nature, but there is a considerable amount of 'hype' involved in the development of AVs, as with many other technology developments. This is reflected in the 'Gartner technology life-cycle' (Fenn and Raskino, 2008), which involves five distinct and important phases in the development and implementation of technological innovations (see Figure 1). They are:

1. technology trigger (i.e. a potential technology breakthrough occurs, early proof-of-concept stories are publicised, and a few usable products exist, but commercial viability is unproven);
2. peak of inflated expectations (i.e. much publicity of successes but not failures, and some companies take action but most don't);
3. trough of disillusionment (i.e. interest wanes as applications and producers fail, and investments continue only if surviving producers improve the product and satisfy early adopters);
4. slope of enlightenment (i.e. the merits of the technology become more widely understood, second and third generation products appear, and more enterprising businesses fund pilots);
5. plateau of productivity (i.e. mainstream adoption starts to take off, and the technology's broad market applicability and relevance become clear).

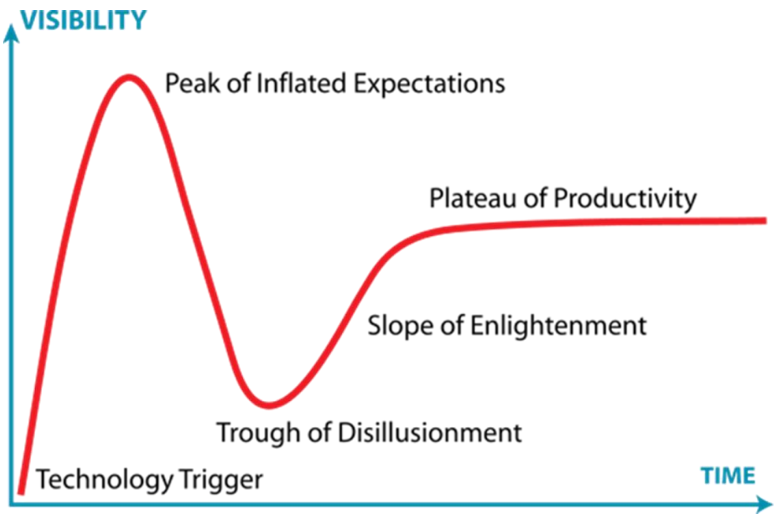

Figure 1: The Gartner Technology Life Cycle

[1] A re-usable plastic board for holding electronic components (e.g. transistors, chips, etc.) that are wired together, to develop prototypes of electronic circuits.

Technology and Hype

Examples of innovative transport technologies that have failed before achieving the final stage include the 'Cyclomer' amphibious bicycle (1932), the 'Amphicar' amphibious automobile (1961), the General Motors 'Firebird IV' (1964), Gibbs' 'Aquada' (2004), Hemmatnia's boat-bike (2015), and the Chinese 'elevated bus' (2016). Another example is the 'helicopter coupe', which was announced and promoted as follows (Stimson, 1951): "Do you want a helicopter that's small enough to land on your lawn and big enough to carry two people? A simple, practical, foolproof machine? It's in production." Stimson's article was accompanied by a picture (Figure 2), which promotes the 'helicopter coupe' as a viable replacement for the car for commuting to/from work. The advertising for the 'helicopter coupe' involved an element of 'hype', to get the public excited about the new technology and stimulate interest in acquiring and using it.

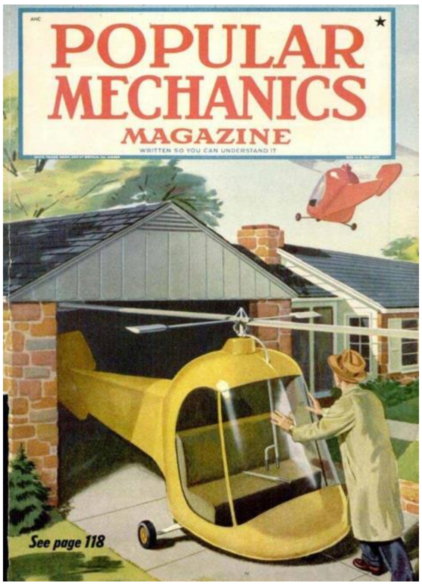

Figure 2: The Helicopter Coupe

There was a more substantial element of 'hype' in relation to General Motors' Firebird IV (Figure 3), which debuted at the 1964 New York World's Fair, and was promoted as a car which would be controlled by automatic programmed guidance systems rather than a human driver and would ensure absolute safety at a speed more than twice the speed possible on expressways in 1964. The Firebird IV, like the helicopter coupe, failed very early in the technology life cycle.

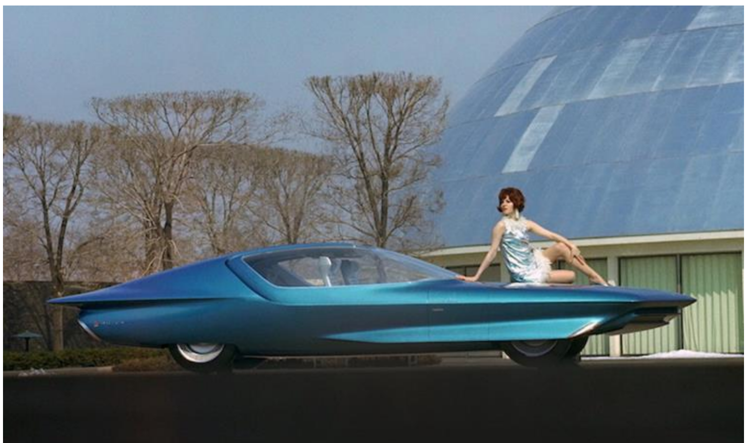

Figure 3: The GM Firebird IV

There is an even more substantial level of 'hype' in the recent proposal from Uber (Holden and Goel, 2016) for a network of small, electric vertical take-off and landing (VTOL) aircraft, that will enable rapid, reliable on-demand transport, and will be more affordable than transport by car (Figure 4).

Figure 4: Uber's Flying Cars

It appears that 'hype' is not confined to the promotion of vehicle technology. For example, Frost (2017) has reported that Siemens has introduced new traffic control software for connected intersections, "… software that allows controllers located at intersections to share information with one another ... allows the on-street network of controllers to adaptively respond to changing traffic conditions in real time … controller can transmit information about a large number of vehicles to a controller at the next traffic signal … allows extra green-light time for the group of cars to move through multiple intersections …". How does this differ from an Area Traffic Control System such as those implemented in some countries in the 1970's?

It is interesting to see that the 2017 Gartner hype cycle shows the autonomous vehicle as having passed the peak of inflated expectations and as heading into the trough of disillusionment (Gartner, 2017).

Technology and Human Factors

The safety of vehicles negotiating horizontal curves has been an issue for many years, because of the centrifugal force on the car and its driver when a car is driven around a curve. This led to the development of tilting cars, which have the ability to change the angle between the road and the car's chassis. This results in a higher proportion of that centrifugal force acting along the 'axis' of the driver (a compressive force) and a smaller proportion acting parallel to the surface of the road and causing body sway. Humans are more 'sensitive' to a force causing body sway than to forces along the 'axis' of the body. Having a tilting vehicle would thus reduce the force which makes drivers less comfortable and which might help drivers sense that they should reduce speed, so they are less likely to reduce speed.

However, having a tilting vehicle does not affect the forces on the vehicle itself (i.e. the gravitational force and frictional force between the tyres and the road surface). Whether the vehicle slides towards the outside of the curve depends upon the maximum available frictional force. Hence, the tilting of the vehicle increases the likelihood of drivers not reducing speed sufficiently and consequently calling upon more friction than is available (i.e. it increases the likelihood of an accident).

Since 2014, Mercedes S-class vehicles have had automatic tilting mechanisms, with the maximum tilt being about 2.5 degrees, which is (fortunately) quite small and is unlikely to result in serious problems, especially given the overall quality of such vehicles. Nevertheless, the interest in developing tilting cars is a classic case of technology being developed without proper consideration of fundamental mechanics and human factors.

During the early 1990s, it was proposed to use ‘in-vehicle speed adaptation’ (ISA) to manage speeds and improve road safety by reducing the probability and severity of crashes. Trials of ISA were undertaken in some countries, including Sweden and the Netherlands. The Lund trial (Hjälmdahl, 2004) involved speed limit ‘reminders’ for drivers and fitting cars with an ‘active accelerator pedal’ (AAP), which applied a resistance to the accelerator pedal if the speed limit was exceeded (acceleration was still possible, by pressing very hard on the accelerator pedal), making it impossible to exceed the speed limit inadvertently.

The aim of the trial was to assess the effectiveness and acceptability (to drivers) of the system. Based on observed changes in speed, Hjälmdahl (2004) estimated that ISA would give reductions of up to 25% and 32% in injury and fatal crashes respectively, and noted that driver acceptability decreased as the intrusiveness increased (e.g. people who drive fast and have a high accident involvement were less accepting). Hjälmdahl noted “there is a clear case for implementing ISA, but there is still nowhere you can buy such a system” (vehicle manufacturers were not interested, perhaps because they perceived that ISA would not assist with sales of their products).

It is worth noting that alcohol and seat-belt ‘interlocks’ have been available for over 20 years, but have also not been widely adopted.

IMPACTS OF AUTONOMOUS VEHICLES ON TRAFFIC FLOW

Impacts on Link Flows

It is well known that as traffic density increases, the traffic flow on a link becomes less stable, with ‘shock waves’ being generated and travelling upstream, causing a reduction in both the flow rate and speed of traffic. The interest in automated driving systems to avoid the occurrence of shock waves is not new, as evidenced by the PATH (Partners for Advanced Transit and Highways) program, established in c.1988 by the Institute of Transportation Studies (University of California, Berkeley) and the California Department of Transportation, to undertake research on an ‘automated highway system’ (Anon. 1994; Anon. 1997; Anon. 1998). In mid-1997, the researchers demonstrated a stream of eight cars (with V2V communication and radar sensors) travelling along a freeway lane at 96 km/h while only 6.4 m apart (giving a capacity of c.4400 cars/hour/lane). They also achieved 112 km/h with vehicles only 3.7 m separation.

A recent theoretical study (Talebpour and Mahmassani, 2016) investigated the effect of AVs on flow stability, and found that it improves as the proportion of connected (V2V and V2I) AVs increases. A more recent experimental study (Stern et al., 2017) found that it is not necessary for all vehicles to be connected and autonomous for flow instability to be greatly reduced; they found that flow instability in dense traffic is greatly reduced with only 5% of non-connected AVs.

More link flow stability means less congestion delay, and Fagnant and Kockelman (2013) estimated that congestion delay would decrease by 60% for freeway links and 15% for arterial links, with a “near doubling” of freeway link capacity (consistent with the PATH project results). However, network capacity is generally governed by node (or junction) capacity, so it is important to also consider junction performance with AVs.

Impacts on Node (or Junction) Flows

It is known that car passengers experience discomfort at lower rates of acceleration than do car drivers, and all AV occupants are likely to expect lower acceleration rates than car drivers, so they can do ‘other tasks’ while travelling. Le Vine et al. (2015) used microsimulation (VISSIM), along with maximum acceleration rates appropriate for rail, and found signalized junction delay was greater for AVs than for driver-controlled vehicles.

Junction capacity and delay are sensitive to increases in critical gap and follow-on gap values, and lower acceptable accelerations means higher values of these gap acceptance parameters (especially the critical gap), giving lower capacity and higher delay at junctions. In addition, junctions are more ‘complex’ than links, and Gomes (2014) has suggested that AVs might therefore be programmed particularly cautiously for junctions, further decreasing capacity and increasing delay.

EFFECTS OF AUTONOMOUS VEHICLES ON TRAVEL DEMAND

Estimates of the change in veh-km of travel with AVs vary widely (Harper et al., 2016), depending upon the sources of the change, e.g.

- +10% to +20% (per AV) ~ due to induced demand;
- +75% (per AV) ~ due to reduced household car ownership;
- +14% to +40% (upper bounds) ~ due to more vehicular travel by the youth, disabled, and elderly;
- -35% to +20% ~ due to reduced travel times, operating and parking costs.

A study (International Transport Forum, 2015) used an agent-based model to assess the impact of the large-scale uptake of ‘shared autonomous vehicles’ in the Lisbon Metropolitan Area, which has:

- 2.8 million inhabitants spread over an area of about 3000 km^2, with 0.61 million cars (only 0.217 cars/person);
- 5 million person-trips/day: 60% by car, 14% by bus, 11% by rail, 8% by bus+rail, 4% by car+rail, and 4% by ‘other’;
- 0.20 million parking spaces in the central city (only 0.33 spaces/car), with 75% on-street and 25% off-street.

The study considered two types of ‘shared autonomous vehicles’:

- autonomous cars, shared sequentially by single passengers (‘AutoVots’), i.e. car sharing;
- autonomous cars, shared simultaneously by several passengers (‘TaxiBots’), i.e. car and ride sharing.

Modelling assumed TaxiBots and AutoVots would deliver the same number of trips (with the same origins, destinations and start times as currently) and would replace all car and bus trips.

The results (Table 1) reveal that:

- the impacts are better if there is a rail service, especially for veh-km of travel;
- the impacts are better for TaxiBots than for AutoVots, except for travel times and waiting times;
- there is a large increase in veh-km of travel, especially for AutoVots and especially without a rail service.

Impact	AutoVots		TaxiBots	
	(with rail)	(without rail)	(with rail)	(without rail)
Change in cars needed	-83%	-77%	-90%	-87%
Change in travel (veh-km)	+44%	+89%	+6%	+22%
Change in peak flows	-43%	-33%	-65%	-57%
Change in parking demand	-89%	-84%	-95%	-93%
Change in travel times	-38%	-38%	-13%	-17%
Change in waiting times	-89%	-86%	-86%	-86%

Table 1: Impacts of Shared Autonomous Vehicles (Lisbon)

The Lisbon study did not identify the environmental impacts (e.g. GHG emissions), but it was suggested that the increase in veh-km would be off-set by reduced emissions per veh-km. However, a study of shared autonomous vehicles (Fagnant and Kockelman, 2014) suggested that while there would be an 11% increase in veh-km of travel, there would be a 12% decrease in energy use and a 6% decrease in GHG emissions.

Both these studies assumed that travel demand would not change (i.e. there would be no increase in trip number and trip length). That is, both studies ignored how people would respond to a decrease in travel costs (time plus vehicle operating costs); there is much evidence that people make more and/or longer trips as costs decrease. Road pricing could be used to limit the increase in veh-km, but road pricing is not attractive to the public and politicians. However, climate change goals (a reduction in greenhouse gas emissions) will not be achieved unless the increase in veh-km is limited.

Thakur et al. (2016) suggest AVs will result in longer trip distances, higher veh-km and urban sprawl, due to a lower value of travel time (more scope for other activities while travelling) and higher trip speeds. They also note that if AVs are shared, the value of travel time will not decrease, as the scope for other activities will be less, and they suggest the effect of sharing (a higher travel time value) might out-weigh effect of lower travel time values with AVs (i.e. veh-km might reduce).

DEMAND FOR AUTONOMOUS VEHICLES

The uptake of AVs will depend upon their affordability or people's willingness-to-pay (WTP). Kyriakidis et al. (2015) surveyed 5000 people in 109 countries, finding that 5% are willing to pay >US$30,000 extra, but 22% are not willing to pay any extra (over the purchase price of a non-autonomous car). They found that WTP is higher for males than females, and WTP increases with income and distance driven. They also found that respondents are most concerned about security (software hacking/misuse), plus legal issues and safety.

A survey of 260 Australasians (Ellis et al. 2016) found that the average WTP is about US$5000 (i.e. about 20% more than non-autonomous car), people aged <36 and 36-60 are respectively 1.4 and 1.2 times more likely to use an AV than people >60, males are about 1.1 times more likely to use an AV than females, and the main attraction of AVs appears to be greater safety, followed by travel time savings.

Haboucha et al. (2017) surveyed 721 people and used choice models to explain the preferences for private-non-autonomous/private-autonomous/shared-autonomous vehicles. They found that 44% prefer private-non-autonomous, a pro-AV attitude has similarly strong positive effects on choosing private and shared AVs, enjoyment of driving has a strong positive effect on choosing private-non-autonomous vehicles, and concern for the environment has a strong positive effect on choosing shared-AVs.

Daziano et al. (2017) also used choice models to assess AV demand, and found that the mean WTP for partial automation is US$3500, the mean WTP for full automation is US$4900, and the WTP varies widely, with demand for automation being split approximately evenly between high, modest and no demand.

EFFECTS OF AUTONOMOUS VEHICLES ON SAFETY

Koopman and Wagner (2017) argue that a coordinated, inter-disciplinary approach, addressing nine areas (computing hardware, software, robotics, testing, security, human-computer interaction, social acceptance, legal issues and safety engineering) will be needed to meet the requirements of ISO 26262: Road Vehicles – Functional Safety (International Organization for Standardization, 2011). They argue that meeting the requirements of ISO 26262 will be a major challenge.

In-depth investigations (Sabey and Staughton, 1975; Treat, 1980; Sabey, 1983) have found that c.90% of road accidents involve human error, and many advocates of autonomous vehicles (AVs) suggest accidents will be reduced by c.90%. For example, Fagnant and Kockelman (2013) state that “driver error is believed to be the main reason behind over 90 percent of all crashes” (emphasis added), and they overlook the fact that accidents typically involve more than one type of factor (road environment factors and vehicle factors are typically involved in c.30% and c.10% respectively). Eliminating the ‘main’ factor might well not prevent the crash.

It is not clear how AV’s will recognise and cope with deficiencies in the road environment, such as warning signs being too close to the hazard, inappropriate warning signs, non-standard temporary traffic management arrangements at roadworks, localised reductions in superelevation at curves, road surface deficiencies (e.g. potholes), and worn pavement markings.

Human factors researchers are particularly concerned about the transition of control (i.e. the switch from highly automated driving to manual driving while in traffic), which will be needed unless the ADS can master all possible traffic situations and all weather conditions, and will never fail. There are two types of transition of control (Vlakveld, 2015):

- planned (e.g. driver takes control when leaving motorway) ~ driver actions are initially slow and error-prone;
- acute (i.e. driver takes control when ADS fails or cannot cope) ~ the driver is probably incapable of avoiding the impending crash, due to lack of situation awareness.

Banks et al. (2018) note that the human factors literature indicates that humans are notoriously inefficient at completing prolonged monitoring tasks. They undertook observations of on-road driver behaviour with a partially automated vehicle (a Tesla Model S operated in Autopilot mode), which requires drivers/supervisors to remain in an active monitoring state, ready to resume manual control if required. They concluded that drivers are not being properly supported in adhering to their new monitoring responsibilities and instead demonstrate behaviour indicative of complacency and over-trust. They suggested that these attributes may encourage drivers to take more risks whilst out on the road.

Developers and testers of AV technology are trying to prove the safety of the technology via on-road use. For example, Blanco et al. (2016) studied Google AV safety based on 1.3 million veh-miles in autonomous mode; they found the crash rate was 8.7 per million veh-miles, which is about 40% higher than the USA national mean of 6.1 per million veh-miles (both reported and unreported crashes). However, they found insufficient autonomously driven miles to identify a statistically significant difference between the AV and non-AV crash rates.

Kalra and Paddock (2016) investigated how much AV road use is needed for statistical significance that the AV fatal crash rate is less than the mean fatal crash rate of human drivers in the USA (1.09 fatalities per 100 million miles), and found that at least 275 x 106 veh-miles of AV use would be needed for 95% confidence. To achieve this, at least 100 AVs being driven 24 hours/day for 365 days/year at 25 miles/hr for 12.5 years would be necessary. It should be noted that the minimum veh-km of fatality-free use increases as the mean fatal crash rate of human drivers decreases (the rate is lower in some countries than in USA) and the desired level of confidence increases.

Kalra and Paddock also show that if the true fatality rate for AVs is 20% lower than that for human drivers, then almost 5 billion miles of AV use is needed for statistical significance at the 95% confidence level. This would entail 100 AVs being driven 24 hours/day for 365 days/year at 25 miles/hour for 225 years.

Kalra and Paddock conclude that it will take many millions of miles of driving to statistically verify the safety benefits of AVs and that it is impossible to demonstrate AV safety is significantly better than human driver safety prior to releasing AVs for general use. They conclude that “this poses significant liability and regulatory challenges for policy-makers, insurers and developers of the technology … a cause for concern among the public”.

Of particular concern is the risk to cyclists and pedestrians resulting from collisions with AVs. It is interesting to note that in 12 November 2014, Google applied for a US patent for “a system for protecting a colliding object from a secondary impact, after an initial impact with a vehicle … an adhesive layer positioned on the front end of the vehicle, a coating positioned over the adhesive layer … upon the initial impact … the coating is broken exposing the adhesive layer to adhere the colliding object to the adhesive layer.” A US patent was granted on 17 May 2016 (US Patent and Trademarks Office, 2016). Google’s action appears to indicate some doubt regarding the ability of their AVs to detect pedestrians and cyclists, and avoid colliding with them.

LEGAL AND ETHICAL ISSUES

Legal Liability

Technology will occasionally malfunction, as evidenced by crash investigations having shown that vehicle factors alone contribute to 2%-3% of crashes, plus another 3%-9% in conjunction with user and/or road factors (Sabey and Staughton, 1975; Treat, 1980; Sabey, 1983). As noted below, AVs have been observed violating red-lights.

There are two types of liability (Leiman and Bilsborow, 2016):

- civil liability for loss or harm due to malfunctions arising from a breach of duty of care;
- criminal liability where there is loss or harm arising from an intentional act (e.g. careless or dangerous driving).

One might be able to get insurance for the first but not the second.

In NZ, the Accident Compensation Corporation covers the costs associated with injuries resulting from road crashes, but it does not cover the vehicle repair costs, which can be large if large modern trucks are involved. Insurance companies have been known to seek to recover vehicle repair costs from individuals whose behaviour results in large costs.

Strict liability entails imposing liability on one party without any finding of intent or failure of duty of care. Some AV suppliers have said they will accept this if the AV was in ‘autonomous mode’ (i.e. the driver has not intervened), but will they accept strict liability if/when large damages awards are made by Courts?

A critical issue is identifying the liability of the manufacturer and/or the driver/supervisor if either:

- a collision occurs after a driver/supervisor has resumed control without the automated driving system (ADS) having made a request to intervene (RTI);
    - is it reasonable to expect drivers/supervisors not to intervene if a collision seems imminent and the ADS has not made an RTI and does not appear to be responding in such a manner that a collision will be avoided?
- a collision occurs after a driver/supervisor has resumed control, in response to the ADS having made an RTI;
    - did the ADS make the RTI so late that it is not reasonable to expect the driver/supervisor to have been able to avoid the collision?

It should be noted that an AV crash at the International Driverless Cars Conference in Adelaide in Nov. 2016 was blamed on the driver for intervening without an RTI (Leiman and Bilsborow, 2016). Uber has tended to blame the driver/supervisor after crashes involving Uber AVs (Levin, 2016).

Sometimes there are faults with the road environment (e.g. inappropriate warning signs, warning signs not located appropriately, worn pavement markings). Determining and apportioning liability (between the driver, AV maker and road authority) is often very difficult, and will mean more work for lawyers and expert witnesses.

Ethical Issues

Sparrow and Howard (2017) argue that it is unethical to sell (or use) AVs if AVs are less safe and that it is unethical to drive traditional cars if AVs are more safe. However, they also note another ethical issue, which is the need to balance higher safety for ‘poor’ drivers (i.e. those whose driving ability is worse than an AV) against lower safety for good drivers (i.e. those whose driving ability is better than an AV). While there might be a benefit to society as a whole, this might well be insufficient to justify imposing a greater risk on those good drivers.

Sparrow and Howard also refer to the tendency of drivers to rely excessively upon driver assistance and automated driving systems, stating that it takes 2−30 sec to regain situational awareness, depending upon driver alertness. They argue that AVs should monitor ‘supervisors’ continuously and should be programmed to slowly and safely park if the ‘supervisor’ is not sufficiently alert.

Consider the following scenario:

- a car is proceeding along a road with pedestrians on the footpaths alongside, when a pedestrian suddenly steps onto the road and into the path of the car;
- there are three options;
    - proceeding straight ahead and perhaps killing/maiming that pedestrian;
    - swerving and perhaps killing/maiming other pedestrians;
    - swerving and perhaps hitting a pole injuring the car occupants?

Who should make the choice between the three options:

- should it be a human driver, who can assess the particular situation and the merits of the options?
- should it made a programmer producing AV software?

If the manufacturers of AVs are not going to be held strictly liable, then a judicial process will be required for determining the level of culpability of the driver/supervisor and the level of culpability of the software programmer(s). That will mean more work for lawyers and expert witnesses.

The dilemma arising in the above scenario has its roots in a classic philosophical ‘thought experiment’ known as the ‘trolley problem’ (Foot, 1967). This was introduced to illuminate the peculiar and sometimes surprising patterns of how humans distinguish between right and wrong. Consider the case of a runaway trolley heading down a track towards five workers who will all be killed if the trolley proceeds on its present course. The only way to save the lives of the five workers is to divert the trolley onto another track that only has one worker on it. Is one justified in diverting the trolley to save five workers but kill one other worker?

Now consider the case of a runaway trolley heading down the track toward five workers who will all be killed if the trolley proceeds on its present course. There is bridge over the track, between the runaway trolley and the five workers. On the bridge is a stranger who happens to be very large, large enough to stop the trolley. If one is also on the bridge, is one justified in pushing the stranger off the bridge and onto the tracks below, if doing so will result in the death of the stranger but the salvation of the five workers?

The trolley problem highlights a fundamental tension between two schools of moral thought, the utilitarian and the deontological. The former favours the action that achieves the greatest good for the greatest number, while the latter asserts that killing an innocent person is wrong, even if they have good consequences. In both versions of the trolley problem above, utilitarians say you should sacrifice one life to save five, while deontologists say you should not.

Cushman et al. (2006) surveyed thousands of people and found that while 89% would re-direct the trolley in the first case above (i.e. displayed utilitarian values), only about 11 percent would display utilitarian values by pushing the large stranger off the bridge. Cushman et al. argued that this inconsistency shows how emotions can affect ethical judgments. Such inconsistency will make it difficult to identify a socially acceptable method for dealing with such moral dilemmas.

There have been several instances of Uber AVs in California not stopping for red-lights (e.g. Levin, 2016). The California Department of Motor Vehicles advised Uber that "it is illegal for the company to operate its self-driving cars until it receives an autonomous vehicle testing permit" (Lee, 2016). The attitude of Uber is very 'interesting'; it stated that "companies should be able to engineer and operate self-driving technology … complex rules and requirements could have the unintended consequence of slowing innovation" (Levandowski, 2016), ignoring the fact that innovation without appropriate safeguards can have the unintended consequence of killing/maiming road users.

It is important to recognise that innovative technology can and does malfunction. An excellent example of this is the behaviour of Colonel Petrov, who was the duty officer at the USSR's centre for monitoring its early-warning satellites over the United States on 26 September 1983, when he had to deal with their early-warning system warning that five intercontinental ballistic missiles had been launched from an American base (Chan, 2017). It was during one of the most tense periods in the Cold War, with the USSR having shot down a Korean Air Lines commercial flight after it crossed into USSR airspace (killing all 269 people on board, including a USA congressman) just three weeks earlier, the leader of the USA (Ronald Reagan) having declared the USSR an "evil empire", and the leader of the USSR (Yuri Andropov) being obsessed by fears of an American attack. Petrov had to decide whether to initiate action which would probably have resulted in the USSR launching a retaliatory attack.

Petrov decided to treat the alert as a system malfunction. He later explained that it was a 'gut decision', based on his distrust of the early-warning system and the small number of missiles that the early-warning system had detected (Chan, 2017). The false alarm was apparently caused by the system misinterpreting sunlight reflected off clouds as highly reliable evidence of a missile launch, due to a computer programming error. The USSR had apparently implemented the system in response to the USA implementing a similar system.

While the situation in 1983 is somewhat different to the situation relating to AVs, there are some 'lessons' to be learned, namely the need to recognise that technology can and does malfunction, the need to avoid being beaten by a competitor, and the need for the decisions to involve a wise human with full situational awareness.

CONCLUSION

It is interesting to note that Litman (2015) suggests the main benefits of AVs will be: reduced traffic and parking congestion; reduced road and parking supply requirements; greater mobility for mobility-disadvantaged people; reduced need to subsidise public transport; increased safety; reduced consumption of energy; reduced emissions (greenhouse gases and pollution). However, given the results of the above-mentioned research, there are real grounds for doubting whether these benefits will materialise.

Regarding the desired characteristic of our transport system, as set out in NZ Transport Strategy (Ministry of Transport 2008), it is very doubtful whether AVs will assist much. The willingness-to-pay data indicate that many people will find AVs unaffordable. Greater integration might be achieved if AV use were to be focused on travelling to/from public transport hubs, but there is little evidence that the promotors of AVs are promoting this use of AVs. The human factors research indicates that AVs will not produce the sort of safety benefits touted by promoters of AVs. While responsiveness is likely to improve with AVs, it is very doubtful whether AVs will improve sustainability. The economic development benefits are likely to accrue to those countries involved in producing AVs. Access and mobility for some sectors of the community (e.g. the mobility disadvantaged) should improve with AVs, and AVs are likely to do little to protect and promote public health by encouraging the use of active modes of travel.

The effect of AVs might well be to reduce network capacity, and there are major legal and ethical issues which are not being addressed properly. The security of AVs and the potential for their ADS being 'hacked', is another major issue, given recent terrorist activities overseas.

Kaplan (1964) stated that “a scientist formulates problems in a way which requires for their solution just those techniques in which he himself is especially skilled.” The manner in which AVs are being promoted suggests that transport problems are being formulated in the same way.

Intelligent transportation engineering requires a more discerning approach, recognising the hype and vested interests associated with some options, and the ‘optimism bias’ displayed by many suppliers/promotors of innovative technology. Decisions should be based on evidence and not ideology.

There are good, well-proven low-technology options for achieving some objectives (e.g. improving traffic safety), and they should be implemented now, rather than waiting for development of high-technology options, which might well not give a significant improvement.

Transportation engineers should be pro-active in setting objectives and specifying what is needed to achieve them, and should not simply be passive recipients of new technology.

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