The ‘Autonomes’ are Coming - This Will Fundamentally Change How We ‘Do’ Road Transportation

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Abstract

This forward looking presentation addresses the issue of the two separate technological tidal waves that we face in automotive and communications technology that will start to transform our roadways sometime between 2015 and 2022. They will result in a paradigm shift in how we 'do' road transportation. The Connected Vehicle will allow road vehicles to communicate with each other and with infrastructure, thereby improving congestion and the efficiency of our road networks as well as improving safety for unimpaired drivers. The autonomous vehicle (or 'autonome' as we call it) will allow vehicle users to be completely disengaged from the driving process for most, or all of their journey, thus effectively removing human error (a factor in 95% of collisions) from the driver/road/vehicle equation. The road safety benefits, business efficiencies, improved mobility and reduced emissions could possibly equate to 4% to 7% improvements in GDP. These technologies will eventually change how we use our road space and parking, the size and weight of vehicles, the need for road furniture, how intersections function, transform public transport as well have major wider societal impacts. In order to maximize the benefits of this technology, and see rapid and significant reductions in collisions, we need to prepare now and ensure that our thinking, policies, regulations and standards can accommodate this impending revolution on our roads.

INTRODUCTION

It is estimated that approximately 1.2 to 1.3 million people will die on the world's roads this year [1]. It is also estimated that in "…three out of five accidents, driver-related behavioural factors dominate the causation of a motor vehicle accident while they contribute to the occurrence of 95% of all accidents." [2] To date, the analysis of road collisions has addressed three key components; the road, the vehicle and the road user. However, the road user is the principle origin of the random events and errors which then result in the vast majority of collisions.

Great strides have been made in recent decades to address the main factors that contribute to road traffic collisions, and driver training has been key in addressing the problem of driver errors and random behaviour. But the road user still remains the weak link in this simplified model of the road system, as their ability to produce random events and errors remains the overwhelmingly significant factor in road collisions.

At the same time, since the development of the modern motor car some 130 years ago, we have seen the car and the road network move from being the medium which has been most influential in shaping our society; even *breathing new life* into societal development, to one which is now beginning to *strangle* society with daily congestion and *choke* us with its fumes. We talk about driver distraction, and yet take a look around at the vehicles waiting at any busy set of lights,and we would not be surprised if you observe a high percentage of drivers clearly focused on a mobile device; ably demonstrating a growing trend of social media addiction. For the younger demographics in particular it seems that *driving itself has become the distraction*.

If we could remove the random-human-error-generating machine from the drivers seat then we could potentially eliminate the 95% of collisions that result form human error. But what if at the same time we could improve the efficiency of the road network and reduce emissions? If that sounds too far-fetched already, then what if we could also dramatically reduce the need for parking in our urban centres and could make them so safe that pedestrians and cyclists could thrive there? To truly test the limits of credibility, what if we could also open up road transportation for a very significant proportion that are currently limited or excluded from *autonomous* travel such as some that are seniors, disabled, medically-at-risk, too poor, un-licensed to drive, too young etc.? Finally, to add to our seeming fantasy wish-list, what if we could achieve all these benefits through private sector initiative, with no infrastructure cost to the public sector?

Well, innovation and the seemingly unbreakable acceleration to technological development provided by *Moore's Law* would appear to provide such a solution that will be arriving, under its own autonomy, to a road near you in the next few years. We are so used to seeing innovation and paradigm shifts in the telecoms industry, from landline, to cellphone (approx.. 97 years), to smartphone (23 years), to first iPhone and Apps (11 years) to the social media revolution (3 years) to what will soon be the next generation of mobile devices such as *Google Glass*, *Microsoft Glasses* (3 years) and possibly even the rumoured *Apple iWatch*. Yet when did we last see a paradigm shift on our roads? We would argue that was when we moved from horses and carriages to the horseless carriage i.e. the modern motor car around 1879 to the early 1900's. It is almost as if we are overdue a paradigm shift to the '*apeless carriage*' as one aptly named contributor to the DriverlessCarHQ website sums it up.

There are two key technologies that can reasonably be expected to come to society's aid in these regards within the next decade. The first, the Connected Vehicle is the one that I suspect

all of us would have predicted to easily arrive first, and at least several decades before the other technology, the Autonomous Vehicle, which is essentially a manifestation of the power of Moore's Law and as one Google Self-Driving Car team member put it "Driving cars, he added, "is the most important thing that computers are going to do in the next 10 years."" [3]

However, on further examination of the operational and business models that might develop with the autonomous vehicle we see that our fantasy wish-list above of benefits and features might only be the 'tip of the iceberg' of what could potentially be achieved.

1. CONNECTED VEHICLES

The Connected Vehicle can refer to either wireless connectivity for the purpose of safety and operations, or for infotainment. We shall limit ourselves to the operations and safety functions in this paper although making the comment as road safety professionals that we are concerned about the competing priorities of keeping the driver safe whilst getting the driver ever more 'connected' with infotainment functionality.

By providing the electronics to allow vehicles to talk to vehicles (V2V) or vehicles to talk to infrastructure (V2I) then additional information can be provided to the driver to improve roadway operation and safety. The combination of both these functions and a wider network is referred to as V2X. It is quoted by the National Highway Traffic Safety Administration (NHTSA) in the US that Connected Vehicles could reduce collisions by unimpaired drivers by up to 80%. [4]

It should be noted that statistics show that very approximately 60% of drivers in collisions are unimpaired [statistics from various sources show wide variation], and that research is still needed to prove that the additional safety and operations information being fed to the driver is not in itself causing a distraction and thus possibly limiting the safety benefits that might otherwise be expected.

This technology is under rapid development in the United States (US), Japan and Europe and is expected to be made mandatory on all vehicles in the US in approximately 2019. [5] There will be a cost to the public purse in deploying the infrastructure side of the V2I system that is not inconsequential. Also, the effectiveness of the system is related to the degree of market penetration, e.g. those benefits that are gained at intersections rely on each vehicle having the technology. The benefits are proportional to the market penetration squared in this instance – so 100% of the benefits can only be achieved at 100% market penetration, and 10% market penetration might only result in 1% of the anticipated benefits.

2. AUTONOMOUS VEHICLES ('AUTONOMES')

It is very encouraging to us that, due to recent advances in technology, the possibility to remove the effect of the road user from the collision equation may now exist. The most widely publicized example of this technology is the Google self-driving car, which has grown out of the work of the DARPA 2005 Grand Challenge $2 million winning team from Stanford University. The Defense Advanced Research Projects Agency (DARPA) is an agency of The United States Department of Defense responsible for the development of new technology for use by the military and, amongst other things, sponsored the DARPA Grand Challenge, thereby providing the incentive that would appear to have accelerated the development of autonome technology.

A number of vehicle manufacturers are also actively developing autonomes, including, but not

limited to, Audi, BMW/Continental, Mercedes-Benz, Ford, General Motors, Volvo, Nissan, Toyota, AutoNOMOS and the Chinese National University of Defense Technology (partnering with First Auto Works).

An autonomous vehicle is essentially a car that drives itself; i.e. it is a robot. Recently enacted Nevada state law (1 March 2012) defines it, and artificial intelligence as follows:

- "Artificial intelligence" means the use of computers and related equipment to enable a machine to duplicate or mimic the behavior of human beings.

- "Autonomous vehicle" means a motor vehicle that uses artificial intelligence, sensors and global positioning system coordinates to drive itself without the active intervention of a human operator. [6]

For ease of use the author (Godsmark) has coined the word 'autonome' in English to refer to these autonomous vehicles throughout the remainder of this paper.

When the history of the motor car is researched it is clear that the basic concept has remained virtually intact, being predominantly a metal frame with wheels at each corner and generally powered by an internal combustion engine. The components of the car and how it works have been incrementally improved over the years, and in the same way the road transportation network has been incrementally improved to cope with it.

However, similar to the effect that technology and social networking have had on the phone, by transforming it from a simple house-bound hard-wired device, to a mobile social platform where the ability to make a phone call is almost a secondary function, so the advances that the autonome brings could similarly revolutionize how we do road transportation; and therefore could significantly impact how we live our lives.

3. AUTONOME CHARACTERISTICS

From a review of the information released by existing autonome developers the following sensors are known to be used in various combinations:

- OPTICAL – this includes windshield mounted cameras that facilitate lane-keeping by spotting contrast changes on the road created by lane markings, and even stereo vision where twin cameras allow a 3D image of the world to be created.

- RADAR – used to track nearby objects, and can be capable of seeing through rain, snow, dust and foliage. This allows the autonome to sense more than a human could in situations where there is visual obscuration, and to sense objects earlier.

- LiDAR – a spinning light detection and ranging system that allows reflections from the spinning lasers to produce a point cloud with a 360 degree view. The autonome can sense movement all around and is therefore fully aware of all objects on all sides and tracks them in real time. Currently the Velodyne sensor that many autonome developers use is in the order of $70,000, but changes in design and economoies of scale mean that Ibeo have said that they wil provide units at $250 each in 2014. [7] With a potential move to solid-state LiDAR sensors in the next few years we could potentially see even

further reductions in cost.

- INFRARED CAMERAS – this system is particularly useful for night-time driving.

- GPS/INERTIAL MEASUREMENT – this system provides the macro view of the vehicles location and is used for general situational awareness and destination planning. All the other sensors provide a micro view of the immediate surroundings.

- WHEEL ENCODER – a wheel-mounted sensor that measures vehicle velocity as it manoeuvers in traffic.

The combination of these sensors means that the autonome can be more aware of its surroundings than a human driver is capable of, as it senses for 360 degrees all around the vehicle and sometimes through visual obscuration. The autonome is capable of taking sensory readings in real time (typically 10 to 20 times a second) which it processes at high speed through the onboard computers. Because of Moore's law the computers being used could be four times faster in four years time.

When autonomes have been developed further they will benefit more from the artificial intelligence characteristic of their programming that allows them to actively develop algorithms to improve their response to the situations they encounter. Once there is an active network of autonomes the development of these algorithms can be shared, so that when an appropriate response has been 'learned' then it can be rapidly disseminated throughout the network. Therefore any unique event requiring the development of a new response will only need to happen once for all of the connected autonomes to 'learn' the appropriate response. A central autonome database can run virtual simulation of all algorithms as they are developed and provide verification that the solution developed is appropriate. The updated algorithms can then be distributed to all connected autonomes. That is to say, should an autonome either encounter a unique situation and/or make a 'mistake', the system will develop, check and verify the response and then disseminate the algorithms so that none of the connected autonomes will make the same mistake.

This is a much closer realization of the 'hive-mind' than human drivers are capable of reproducing. Currently most jurisdictions do their best to train drivers and instruct them how to identify and deal with general and a few specific hazards, but once training has finished the majority of drivers will then mostly learn from their own driving experiences and their own mistakes. However, no driver is able to know of or learn all of the lessons from all drivers, whereas every connected autonome will be theoretically capable of doing this.

It is the author's expectation that the combination of superior sensory information, more rapid processing of data and hazard analysis and then dissemination and hive-mind-learning that will lead to autonomes being identified as the safest form of road transportation.

4. THE STATE OF AUTONOME DEVELOPMENT

Autonomous devices have been used by the military and industry for many years. Probably the closest working example of a self-driving car is the Komatsu Frontrunner Autonomous Haulage System (AHS) (Figure 1), used in Chilean and Australian mining since 2008. Following a successful trial of ten Komatsu AHS 290 tonne trucks in use since 2008, the international mining

company Rio Tinto placed an additional order for another 150 AHS trucks in November 2011. This level of investment by a major international business suggests that autonome technology is now a credible alternative in certain mining applications.

The achievements of the Google team have been the most widely publicized to date. A fleet of their self-driving cars (Figure 2) had, by April 2013, completed over 500,000 miles of testing on public roads, recording everything that they saw and the use of artificial intelligence has allowed the system to develop its own rules using the programmed algorithms. A key metric however is that the Google self-driving cars have completed 96,000 miles without safety critical human intervention [8]. When compared with calculations carried out by Bryant Walker Smith of Stanford University the authors own calculations suggest that this gives a 45% confidence level that the Google self-driving car will crash less than a person. [9] Clearly this metric is insufficient on its own to demonstrate that these vehicles are safe enough for public use, but it does demonstrate how far the Google program has developed since it started in 2009.

Figure 1 A Komatsu 930E Using the Frontrunner Autonomous Haulage System technology

The Google car has been given the freedom to drive itself, with co-pilot drivers ready at any moment to assume control, over a variety of road networks and terrains and through various traffic and climatic conditions whilst encountering numerous hazards. The results of these trials appear to be very promising, and the Royal Academy of Engineering Report of August 2009 that states “Robotic vehicles are technologically closer than most people might think” [10] as well as numerous magazine articles and press releases from autonome developers, have convinced the author that in a relatively short space of time the technology will result in self-driving cars that will be significantly safer than even a very good human driver. The ability of the autonomes to ‘learn’ as they go and then disseminate key data and developed algorithms to other

autonomes means that it is possible that an unusual road situation may only need to be encountered once by a single autonome and then all other autonomes that the information is disseminated to will then be better prepared for any similar situation.

Figure 2 The Google autonome (on a Toyota Prius platform)

Through one author's (Godsmark) research work with the Facebook group DriverlessCarHQ we have been able to discern through unique license plates on photos posted on various photo-sharing websites that the Google fleet could be 32 vehicles or more, and based on their announced progress mileage we estimate that the fleet might be accruing approximately 1,000 miles of testing every calendar day on average as at April 2013. [11]

In parallel with the development of the technology, the developers of autonomes have already had to address some of the wider issues that accompany this paradigm shift in how we 'do' road transportation. For instance, in most jurisdictions special permission has to be gained from the appropriate authorities to use the cars in self-drive mode. In February 2012 the State of Nevada approved regulations for self-driving cars that outline the requirements for companies to test autonomes on its roads [12]. In September 2011 the AutoNOMOS labs 'MadeInGermany' autonome (Figure 3) was driven for 80km in the Berlin traffic following certification by the authorities in June 2011 [13].

Since then the US States of Florida and in particular California have enacted autonomous vehicle bills, as well as the District of Columbia (Washington D.C.). In addition, as of April 2012 a further thirteen US States, including Michigan and Texas had bills for autonomous vehicles in process. [14] There appears to be a clear trend within the US that all of the individual States and jurisdictions will eventually have formalized the status of autonomous vehicles and provided

regulations to formalize their testing.

As of April 2013 three companies have completed the required 10,000 miles of testing and qualified for the official Nevada red 'infinity license plate': Google, Continental and finally Audi. [15]

It is also worth noting that the California Autonomous Vehicle Bill SB1298 requires further action by the start of 2015:
"The bill would require that the Department of Motor Vehicles adopt regulations as soon as practicable, but no later than January 1, 2015, setting forth requirements for the submission of evidence of insurance, surety bond, or self-insurance required by the bill and requirements for the submission or approval of an application to operate an autonomous vehicle, including any testing, equipment, or performance standards, as specified, and to hold public hearings on the adoption of any regulation applicable to the operation of an autonomous vehicle without the presence of a driver inside the vehicle. The bill would provide that federal regulations promulgated by the National Highway Traffic Safety Administration supersede state law or regulation when found to be in conflict." [16]

We especially note the intent here to develop regulations and standards that would be applicable "…*to the operation of an autonomous vehicle without the presence of a driver inside the vehicle.*" It is the authors view that once such unmanned operation is certified safe then a paradigm shift occurs which will transform our roads first, and then society.

Figure 3 The AutoNOMOS Labs 'MadeInGermany' autonome

5. WHEN WILL AUTONOMES ARRIVE?

As can be seen from the videos released by a few of the autonome developers, and the statement from AutoNOMOS labs that "…autonomous vehicles could be already used in private roads since the technology is mature.", [17] then it would seem that it is only a matter of time

before the developers consider that the technology is mature enough for the public road network. The aim of the majority of the motor manufacturers that are researching and developing this technology would certainly appear to be in order to provide autonomes for use on public roads, and as we have seen from California bill above, for the autonomes to be able to function unmanned.

Only as far back as the first quarter of 2012 no exact dates had been given by potential manufacturers as to when autonomes would begin to roll (themselves?) off of production lines, Professor Will Stewart of Southampton University, UK, co-author of the report by the Royal Academy of Engineering in the UK, dated August 2009, is quoted in the press as saying "I think in ten years 30 per cent of trucks could be machine-operated." [10].

In October 2011, General Motors said in an official company news statement "Vehicles that partially drive themselves will be available by the middle of the decade with more sophisticated self-driving systems by the end of the decade." [18].

However, since Google's public statements (approximately every additional100,000 miles of testing on public roads) and the rare official self driving car blog updates, the automakers appear to have been under pressure to demonstrate that they are 'in the game'. As a result the following announcements have also been made:

- Volvo (Chinese owned) – 'Crash-proof cars by 2020' (relying on semi-autonomous and Advanced Driver Assist Systems (ADAS) technology) http://www.motorauthority.com/news/1082032_volvo-predicts-crash-proof-cars-by-2020-video?goback=%2Egna_4731574
- "BMW Group and Continental Automotive are collaborating to improve driver assistance systems, otherwise known as "highly automated driving." With this partnership, BMW hopes to have fully automated driving "ready for implementation by 2020."" http://www.automedia.com/Blog/post/BMW-Pledges-To-Have-Driverless-Cars-By-2020.aspx?goback=%2Egna_4731574
- Nissan: ''Driverless Cars Coming To Showrooms By 2020, Says Nissan CEO Carlos Ghosn" http://www.forbes.com/sites/danbigman/2013/01/14/driverless-cars-coming-to-showrooms-by-2020-says-nissan-ceo-carlos-ghosn/?goback=%2Egna_4731574
- "Mercedes-Benz claims it is in the best position to win the race to create the world's first customer-ready self-driving car.." http://news.drive.com.au/drive/motor-news/mercedes-racing-to-selfdriving-car-20130115-2crgk.html?goback=%2Egna_4731574%2Egde_4731574_member_204902517

Following a press launch to announce the intention to develop legislation to allow autonomous vehicles to be developed on California's roads an article in Bloomberg Business Week in March 2012 quotes Bruce Breslow, director of Nevada's Department of Motor Vehicles. The article states 'Breslow said he thinks autonomous vehicles will be operating on the state's roads in three to five years.' [19] It should be noted that as a key person in the jurisdiction of Nevada and approached by Google regarding the use of autonomes in that State, Mr. Breslow has since come into contact with other autonome developers who are keen to take advantage of the opportunities afforded by Nevada as an early adopter. Mr. Breslow is therefore likely to have a better understanding than most on the likely implementation timetable for autonomes.

Since then Google co-founder Sergey Brin, at the California autonomous vehicle bill signing held at Google headquarters on 25 Spetember 2012 said "You can count on one hand the number of years it will take before ordinary people can experience this." [20] At the time we took

this to indicate by 2017. However, following this in the early months of 2013 a number of different Google self driving car team members have made statements along the lines of "We expect to release the technology in the next 5 years." – which would indicate 2018.

Given the above statements, and from viewing numerous online videos of the developers' accomplishments, it is the author's opinion that the Google technology is probably even more advanced than that of the conventional vehicle manufacturers and other developers. This would also seem to be the view of a number of leading experts interviewed by Wired [21], one of whom responded on the statement that Google had essentially grabbed pole position for autonomous driving by pointing out that Google have made the bold move to put the emphasis on software over hardware and that the Google way means that their vehicles work with the existing highway system, and doesn't have to wait for the highways to get intelligent.

In support of this our research has found that Google has probably the best developed artificial intelligence research teams of any company in the world and they have published copious research findings demonstrating ground-breaking advances in this area.

Therefore, a date for autonome production for sale to the public by 2018 would appear to be plausible. However, the technology and its likely delivery date may not be the limiting case for the successful implementation of autonomes on the world's roads at this point in time.

6. ADVANTAGES AND DISADVANTAGES OF AUTONOMES

There are numerous advantages and disadvantages of autonomes which will be experienced over time, some of which will be particularly noticeable as the proportion on the road reach a critical mass, which include:

6.1 Direct and Indirect Advantages

The following are some of the direct advantages of autonomes:

- The expectation of a significant reduction in accident rates as the technology removes the human factor (errors and random events) and associated reduction in societal cost. (The author estimates that the potential societal cost saving in Canada due to collision reduction could be as much as 4% of GDP, but this is subject to further research and verification). The autonomes will be programmed to be a better driver than a human, with 360 degree vision of hazards (being monitored up to twenty times a second on current development models), significantly better reaction times than a person and with sensing technology that can currently include optical, LIDAR and radar - which combined with the 360 degree view achieves greater situational awareness than any person. Also, being an artificial intelligence machine, it can develop its own algorithms and benefit from shared algorithms from other devices, thus 'learning' from the accomplishments/mistakes of every autonome in the network.
- Reduced emissions due to improved driving efficiency and reduction in vehicle numbers on the road required to carry out the same volume of work. Google presentations confirm the findings of the Rio Tinto autonome operations that these vehicles can be programmed to consistently brake and accelerate smoothly thus being more fuel efficient, reducing emissions and subsequently incur less wear and tear and require less maintenance.
- The opportunity to maximize road capacity by reduced vehicle headways, platooning, or even lane splitting or lane-sharing if narrow vehicles are used.

- The driver is now a passenger and; therefore, free to use travel time more productively rather than consider it as lost time.

Indirect advantages of autonomes include:

- Opportunity to re-engineer the road network to reduce lane widths, reduce intersection sizes, remove the need for grade-separated intersections and remove unnecessary roadside furniture (street lighting, signing/lining, signalization, crash barriers, parking spaces immediately outside structures as autonomes can park themselves remotely, or continue onto other transport assignments without a driver etc.).
- As a result of the above reduction in infrastructure requirements the cost of new road construction and road network maintenance will fall.
- Driver's licenses will no longer be required.
- The need for law enforcement on the roads will reduce to the point where it is no longer needed as a separate function/department within police forces.
- Vehicle insurance could be radically altered and reduced.
- Environmental benefits from the reclamation of excess paved areas, particularly in the urban context.

6.2 Disadvantages of Autonomes

Disadvantages of autonomes include:

- Of particular relevance to the target audience of this paper - Over time many transportation professionals will find that their jobs are significantly impacted and that the need for some existing specializations will reduce whereas new specializations are required.
- Employment displacement will occur as it has done with all major technology revolutions throughout history. Employees, particularly drivers, in many trades and industries will find pressure for their jobs to be replaced by autonomes.
- As autonomes become more prevalent and rules and regulations favour their usage over the inefficiencies of human drivers then the personal freedom to travel when and how society currently enjoys will be slowly eroded. Many drivers have expressed the simple joy of driving themselves and see autonomes and legislation limiting human drivers as limiting their rights and freedoms.
- The opportunity for increased governmental control of how autonomes and human driven vehicles interact and how and when autonomes can travel.
- 'Big Brother' will have ever more detailed information about individuals and their travel habits.

7. KEY CHALLENGES AND OPPORTUNITIES

In relation to some of the advantages and disadvantages outlined above, there are key challenges that will be faced before and during the implementation of autonomes, as well as some very distinct opportunities.

7.1 Key Challenges

From research of recent articles on autonomes, discussions on technical forums and discussions following initial presentation of the author's work in this area, the key challenges

would appear to be:

- SECURITY – any device that can be programmed and has an upload/download link is open to numerous forms of security breach. The possibility of an entity gaining control of one, or even a fleet of autonomes to use them as programmable 'missiles' is an extreme example, but one that must be addressed to ensure government and public confidence in the security of this new technology.
- LEGAL/REGULATORY – all existing laws would appear to be based upon the explicit or implicit assumption that a human driver is in control of the vehicle and responsible for its actions. Just as Nevada, Florida and California have passed new laws, so all jurisdictions that wish to permit this technology will have to determine what changes are necessary for its orderly introduction. If jurisdictions only permit this technology to be used with a responsible licensed driver at the wheel then many of the main advantages will not be realized, however this may be the only acceptable solution in the early stages of adoption.
- INSURANCE – there will be incidents involving autonomes and a legislative framework must be developed in advance so that the responsibility of all parties involved is understood prior to their operation and use. The autonome manufacturer, the body responsible for programming, the autonome owner, the autonome user, the police, the highway authority etc. must all have an understanding of the limits of their liability and have accepted those limits. It has been proposed that a system similar to that set up to bring order and protection to vaccine use may be appropriate to apply in this situation as well.
- USERS – the autonome users must overcome any fear or concerns regarding safety and their trust in the technology.
- UNIONS/TEAMSTERS – there are numerous professions and trades that will be significantly affected by the implementation of autonomes. Trade Unions in particular could provide major resistance as they seek to protect their jobs in the face of losing them to this technology. Professional drivers such as long haul truck drivers and taxi drivers are obvious jobs that will be affected. However, jurisdictions will also need to consider reducing training of medical staff such as trauma surgeons given the potential savings in collisions that could result as uptake of the technology increases.
- STANDARDIZATION – just like any other new technologies there are a number of developers using different platforms, sensors, software, algorithms etc. all competing for a future market share. It is vital that to maximize the efficiencies of these different autonome systems that they communicate with each other and any Connected Vehicle systems in a globally agreed way. It would also be a significant benefit if the 'hive mind' concept is harmonized such that the different platforms can learn the lessons already learned by the other platforms.

7.2 Key Opportunities

The author has identified the following key opportunities:

- SAFETY – ultimately, when the sub-optimal behaviour of human drivers has been removed from the road network then theoretically collisions can be reduced by up to 95%. For a country like Canada where the societal cost of collisions in 2012 is estimated to be of the order of $62 billion (4.9% of GDP), then the true potential savings in the future might be measured in full percentage points of GDP.
- BUSINESS EFFICIENCY – many businesses that have truck fleets or rely on vehicle movements will see the opportunity to reduce labour costs and improve logistical efficiency, especially as autonomes will not be bound by driver fatigue or limited work

hours in the same way.

- PUBLIC TRANSPORT – the autonome has the potential to revolutionize public transport and could present the possibility of a level of service and cost effectiveness that will challenge existing bus services, LRT, coaches, trains and even short range flights. Jurisdictions currently considering or planning public transport facilities that will be implemented in more than the next five years should give some consideration to an equivalent service provided by autonomes to determine the appropriateness of their current plans.
- ENVIRONMENTAL – an autonome has the potential to be more fuel efficient than the equivalent vehicle driven by a human driver as it can be programmed to consistently drive in a manner that will conserve fuel. In addition, closely spaced platooning will allow autonomes to travel both more quickly and safely and using less fuel than human drivers are currently legally allowed to. As autonome use develops we might expect the number of vehicles on the road to reduce as some societies move away from an expectation of one car per person and learn to share use and save costs. There would therefore be environmental benefits because fewer vehicles will be required to replace the attrition from existing fleets during the early years of autonome adoption. Also unnecessary road space will be reclaimed for societal use.
- SOCIETAL – just as smartphones have led to an explosion in the use of social media, so the implementation of autonomes could result in similarly unexpected societal changes and benefits that will transform lives beyond how we travel between locations. Ultimately autonomes will be able to be sent or summoned remotely without a human occupant. Humans will be able to sleep, work or play whilst in an autonome – being free to carry out reasonable activities within an accepted envelope of safety as determined by the law. Autonomes are likely to be one of the forms of robot with early and wide uptake; as other robots are developed so autonomes will be able to transport other robots. Autonomes have the potential to transform the lives of disabled people that are limited by existing vehicular transportation; especially the blind and those unable to enter and exit and drive without considerable effort.

8. THE TRANSITION PERIOD

Following the advantages above, many will only be fully realized when the vast majority of road vehicles are autonomes, as for instance the full advantages of autonome platooning and efficient intersection negotiation without signalization will require reaction times that are beyond virtually all human drivers. Reduced lane widths, that autonomes can navigate with ease, would create far too many hazards for the average driver over anything other than short distances. Possibly the greatest advantage of the reduction of traffic collisions to as little as 5% of current levels and the massive societal cost reduction that accompanies this, can only be fully realized when humans are no longer directly responsible for making real-time decisions on the road network.

The ultimate autonome vision therefore requires the removal of human drivers from the road. By this time, if it should occur, associated societal changes will have occurred which present a whole host of other challenges as to how our daily lives interact with road transportation.

However, before any such ultimate vision can transpire, there will be a transition period, likely to be several decades long, where humans and autonomes will have to learn to share the road space.

A few of the questions that will be raised during this transition period include:

- Will humans and autonomes share the roads harmoniously?
- Will human drivers take advantage of the 'predictability' of the autonomes?
- Will humans and autonomes be treated equally in the eyes of the law?
- Should humans and autonomes be treated equally in the eyes of the law?
- Can legislation, regulations, standards and guidelines for our road networks be made flexible enough to cope?
- Will autonomes actually create additional hazards that result in collisions?
- Will road collision statistics reflect the anticipated improvements? – i.e. is there a 'critical mass' point at which autonome benefits are seen?

The readers and author can make educated guesses at answers to the above, but clearly more research is required at the date of this paper.

8. SUMMARY AND ANALYSIS OF KEY ROAD SAFETY ISSUES

The case that autonomes could ultimately reduce global road fatalities and collisions by up to 95% appears to be a strong one, given the maturity of the technology and the logic behind removing driver error, the greatest causative factor, from a road collision system view.

However, the transition period as autonomes appear and become more common on road networks will be a challenging time.

For autonomes to even be allowed on the roads in most jurisdictions, then the legislative framework will have to be sufficiently developed to accommodate this paradigm shift. The greatest benefits will be gained if there is harmonization between jurisdictions and also between the different autonome manufacturers and the algorithms programmed into the autonomes.

A balance will need to be found between the ability of autonomes to drive both rapidly and safely, against the fact that autonomes will also be capable of driving slowly and steadily and therefore more economically. In both of these modes the autonome will be able to consistently outperform human drivers. Yet neither mode appears suited to the existing average network traffic behaviour when the wide range of human emotion is exhibited through the random driving styles we see every day on busy roads. The autonomes will therefore have to operate sub-optimally in order to cater for the lower standard of human driving. Given that on the overall road network this will result in road collisions that could have been avoided, increased fuel consumption, pollution and greenhouse gases and avoidable costs to businesses, it will be interesting to see if societies choose to embrace the benefits of autonomes and what compromises are needed, if any.

9. THE PARADIGM SHIFT AND IMPLICATIONS

Following significant further investigation of the potential impacts of the deployment of autonomous vehicles it appears that the overall impact on society could be even greater than that of the internet. In a sense the internet was essentially a 'virtual revolution', whereas this will be a 'real revolution'. Why do we think this?

To understand this more clearly, then the paradigm shift itself needs to be understood and put in the context of the societal norms where it will be introduced. For this paper we will confine ourselves to the North American context.

Several of the special guests that have been permitted rides in the Google self-driving car in public roads have made similar comments along the lines of Coby Chase, TxDOT's director of government and public affairs at the Texas Transportation Forum in February 2013: "The remarkable thing was that it was a little unremarkable." [22]

Similarly the paradigm shift appears unremarkable – it is simply that a vehicle can travel unmanned. But when we start to unravel this novel concept then we find that it has profound and remarkable implications for society:

1. A vehicle that can drive unmanned can do work by carrying people and goods.
2. A vehicle that can do work can make money for its owner.
3. A vehicle that can make money will be in great demand in a free-market economy.

But again, this initial unravelling doesn't reveal the breadth of the impact of the autonomous vehicle. So allow us to sketch out a possible implementation scenario that will unravel the new paradigm a little more.

Once the autonome is certified safe for unmanned use then a number of businesses/sectors will be more than ready to purchase this technology. In fact we expect that their orders will have been placed many months or even years in advance, as if they don't utilize the cost saving and efficiency benefits of the autonome technology then they will lose out to their competition:

- The trucking industry – by removing driver costs, reducing fuel costs and reducing maintenance costs then they can maintain profit margins and still the price of goods in shops will reduce.
- The taxi industry – any good taxi driver knows this technology and 'this day' is coming. For a New York Taxi the driver is approximately 57% of the cost of a ride [23] – it is difficult to see how they could compete with autonomous taxis.
- Car rental companies – most users will quickly realize that that hiring an autonome only when transportation is needed will be cheaper than a longer hire of an ordinary vehicle that is likely to be unused most of the time. Also their rental auotnomes will suffer less damage, require less maintenance and overall be cheaper to run and allow them more flexibility on not requiring returns to a specific location.
- Car-share companies – their business models will naturally migrate to autonome technology as it a simple progression of their existing models.
- Ride-share companies - their business models will naturally migrate to autonome technology as it a simple progression of their existing models.

You will note that a common theme is emerging here. The early adopters all run fleets. But what will happen is that (apart from the trucking industry) their business models are converging – they will now in fact be competing against each other.

But what about the average person? The more entrepreneurial minded individuals will realize that with an autonome that they will be able to use it for their commute to work, but they can then assign it to an ad-hoc autonome taxi company operating in the 'cloud' that will, for a small fee, hire it out to those in need of transportation, at cheaper rates than even the taxi companies. Users in need of a vehicle simply use a mobile device such as a smart phone or Google Glass etc. and send the details of their travel requirements to the cloud. Before the time that the vehicle is due to be returned to the owner then the cloud based company can have arranged for any maintenance, cleaning and re-fueling. Thus the owner might actually make a small daily profit, even allowing for depreciation – which is a considerably better financial situation than an

ordinary car which sits idle for around approximately 95% of the day on average.

Again – the fleet theme is repeated. This time with private individuals and their low overheads and low profit expectations against the aforementioned business based autonome fleets.

But what about public transport? Well it is easy to see that bus services could be severely impacted. They require riders to travel to and from fixed bus stops and will therefore have a lower level of service and probably have a lower quality feel than using an autonomous taxi. Those buses serving high density corridors will always have the advantage of being able to densely pack passengers into a single 'metal box', but on any routes where road space is not at a premium then some, if not all ridership, could be lost to the autonomous taxis. This leaves the bus operators with an interesting dilemma – of how to adapt their operational and business models to survive, or even thrive in this new environment. The use of autonomous buses is certainly an option, but research is definitely needed to determine what might be an optimum solution.

And LRT? Again the principle of high density corridors ensures the continuing need for LRT, but the lower-ridership peripheral routes may need review as to their continued viability. What is of concern to the fiscally minded, is whether the operational, business and revenue models for proposed LRT lines or extensions are sufficiently robust for their plans and designs to continue being designed from within the existing paradigm. When the large capital costs of LRT construction is taken into account, and the operational subsidy that most service require, an autonomous taxi alternative, funded by the private sector, may begin to look a very attractive alternative.

So there appears to be market forces at work, because autonomes can make their owners money, that could lead to rapid deployment and a certain degree of market penetration. But there is another very significant market dynamic, or trend that will come into play as well. That is the rapidly growing trend of the 'shared economy' which is well illustrated by the rapid growth of car-share and ride-share services, especially in trend-setting hubs such as San Francisco and other Californian cities. This is clearly seen in the statistically significant reduction in ownership of cars by the younger demographics and the rising average age of gaining a driving license. Much of this is related to greater awareness of environmental and sustainability issues from education, as well as a growing addiction to social media – where driving has now become the distraction.

Proof can be found in the claims from car-share companies, such as Car2Go who operate in Calgary who in conversation with the author (Godsmark) claimed that a single Car2Go vehicle can replace up to twenty privately owned vehicles. This principle can be expected in autonome fleets, and a study by the Earth Institute (EI) of Columbia University "Transforming Personal Mobility" indicates that in a successful autonome fleet one autonome could replace approximately six private cars. [24] In addition, the EI authors found that by relinquishing private car ownership that the average person could reduce their annual transportation costs by approximately 40% when using conventional cars as the base for auotnomes. But when ultra-lightweight electric powered autonomes are used then the cost can reduce by up to 80%. For an average person these savings could be significant multiples of their current disposable income and could result in substantial quality of life improvements.

So overall it appears that there are safety, efficiency, financial and environmental benefits for users to switch from privately owned cars to autonomes, but even greater advantages if they relinquish ownership of private vehicles and use fleet autonomes. Those users that continue to

drive themselves will actually be sub-optimal road users in a number of situations, especially in dense traffic as for safety they should maintain larger headways due to slower reaction times.

How could this all affect our cities? Well this is where we see a very interesting challenge emerging. Most North American cities it seems would like to make their streets much more liveable and desirable places to be – hence the rise and rise of concepts such as 'reclaim the streets' and 'complete streets'. The desire is for pedestrians and cyclists to be actively encouraged and to remove as much fast-moving, dangerous and polluting traffic from urban streets as possible. We see so many opportunities to move towards these ideals with the deployment of autonomous vehicles.

Firstly the requirements for parking will reduce dramatically as the autonomes can simply drop riders off and then either proceed to free parking outside of the inner city area, or be available for the next hire through the cloud. This gives rise to the interesting question of 'What do we want to do with this reclaimed land and these re-claimed parking structures?'. We suspect that the urban planners and the private developers could have diametrically opposite desires here – which is why it could be very important for city planners to review policy at an early stage.

Secondly, because of the efficiency that autonomes will move through inner city streets, as mentioned earlier, the human drivers will be highlighted as the sub-optimal element.

Thirdly, because autonomes will be the most courteous and safest of drivers, the opportunity to promote pedestrian and cyclists facilities above autonomes will be an enticing possibility for urban planners.

Finally, as autonomes won't crash as much there will be a desire for them to shed up to three quarters of their weight. That is the weight that current vehicles carry simply because we require that they protect us in the case of a crash, which 95% of the time will be as result of human error.

When these factors are combined it is possible to identify that there would be a growing desire to ban human drivers from a city core and create something like the London Congestion Charging zone, where only autonomes are allowed inside the defined zone. With the ideal conditions to optimize autonome fleets we expect that ultra-lightweight electric autonomes could become the standard vehicle to journey within the zone providing safety, operational efficiency, financial and environmental benefits. Pedestrians and cyclists would feel much more secure than with human drivers and the possibilities to improve the streetscape and promote community living and improve quality of life could have urban plannings in some form of planning heaven.

If Google do release their autonome technology to the public in 2018, and autonomes are certified safe for unmanned use in say 2020, then taking a very optimistic view with this technology we predict that the first city might institute an autonome-only zone possibly as soon as 2023. We may even see a race for the first city in each country to implement such a zone as the benefits could be very appealing to both city centre businesses and residents.

9. THE RESPONSE OF THE TRANSPORTATION PROFESSION

Given the potential of autonomes to massively reduce global road fatalities and injuries, and to

make efficient use of existing infrastructure the transportation profession needs to consider its role in the deployment of this technology and policies, regulations, standards and systems that need to be in place to assist its implementation.

The profession has a duty to the public to make itself aware of this impending technological tidal wave that will result in a never-seen-before paradigm shift in how we do road transportation. It is our duty to predict the changes that will need to be made to infrastructure, legislation and travel modes. Our societies and how we live our daily lives will be impacted by this technology. If we are to capture the massive potential road safety and efficiency benefits then we need to adjust our thinking, our road network models and understanding of how they behave, our standards, our guidelines and our expectations.

We need to be prepared to change our plans and policies that have been developed within the existing paradigm and and re-learn how to create efficient, appropriate and robust designs within the new paradigm.

The author proposes that as transportation professionals we begin to actively engage with the researchers, engineers and businesses that are developing this technology and ensure that they are aware of the impact of their work on what we do. Although the autonome system itself is the responsibility of the autonome developers, the operation and the physical infrastructure and geometry of the road system itself lies with engineers and the highway authorities and each party would benefit from understanding the limitations and nuances of each system. We should point out that our profession is a stakeholder in the development of the technology and that we can play a vital part in both its development and the framework of laws and regulations that will allow autonomes access to public roads.

The profession should also engage with the politicians who will be responsible for developing the policies that surround this technology, in order to positively influence the message that autonomes can be a very good thing for society and that the potential road safety, business and environmental benefits should be given full consideration so as to maximize potential benefits. We should also engage with those responsible for the development of the legislation to ensure that they too understand that well crafted laws will allow the technology to function in an optimal way and thereby achieve rapid and significant road safety benefits, whilst protecting existing road users.

As a profession we are either a part of, or consulted by various standards bodies and regulators and it is important that we raise the awareness of this technology and understand its potential. We must think through the consequences of this technology as it will impact on many areas of everyday life that are in turn affected by the road transportation network. We really do need to re-think how we do road transportation in order to maximize the benefits and we must then capture this thinking in our standards and regulations, yet make them adaptable enough to accommodate additional benefits that we may not yet have foreseen. Perhaps very similar to the way that the development of the cellphone, and then smartphone, has unleashed the possibilities of social media; so the advent of the autonome will have unexpected benefits and challenges.

More than ever we must seek to communicate across jurisdictions and international boundaries in order to ensure that the global transportation community is working in a harmonious way. We must raise global awareness of how important this technological development is in our continuing struggle to reduce the number of people killed and hurt on the world's roads.

Because autonome technology could not just transform our roads, but could impact on almost every aspect of daily life and transform society, we make the recommendation that the Federal Government give consideration to establishing a

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