DIGITAL DRIVING:

THE FUTURE OF ROAD TRANSPORT

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Motor vehicles provide us with one of the great personal freedoms of the industrial age and they are a central driver of our modern economies. But motoring is also the most dangerous activity humans undertake regularly. Over 1.25 million people are killed globally on the roads each year, the equivalent of 300 jet planes crashing. Millions more suffer injuries so severe their lives are devastated[1].

However, motorised transport in all its forms is yet another feature of the industrial era that is now undergoing severe disruptive transformation caused by digital technology. In the longer term the positive results of this disruption will include far greater safety, a massive reduction in greenhouse gas emissions and increased efficiency of road use. The negative long-term outcomes will include some loss of personal freedoms, disruption for the traditional automotive industry and widespread unemployment for professional drivers.

In developed nations driving has been getting steadily safer over the last few decades thanks to driver protection technology (seat-belts, air bags, ABS braking, etc.) but driver, passenger and pedestrian safety will soon be taking a huge leap forward as networked digital technology makes road vehicles semi-

autonomous at first and then creates vehicles that need no human driver. Computers are about to save us from ourselves.

How Long Until Cars Drive Themselves?

The concept of "robotic cars" is exciting. Today's techno-pundits are breathlessly forecasting that our roads are about to be filled with digitally-equipped vehicles which are so good at driving themselves they won't even have steering wheels or brake pedals. They suggest that road accidents will become a thing of the past as inter-communicating robotic cars, trucks, vans and buses assume full driving control and take over this risky task from fallible humans. Many commentators add that the need for personal vehicle ownership will disappear in urban areas as passengers summon autonomous cars with Uber-style apps to take them wherever they want to go.

These enthusiastic pundits also suggest that new entrants to the car manufacturing market – e.g. Apple, Google, Uber – are about to sweep aside the established automobile makers and a new age of lighter, cleaner and safer fully-automated personal transport is about to arrive.

But the future won't be like that – at least not within the next 30 years or so.

It's a common mistake in forecasting to look at emerging technologies and imagine a future based on their projected curve of development, but without giving much thought to public acceptance and legal practicalities. In essence, amateur forecasters often suggest that major social changes caused by technology development are just about to happen. But experience teaches us that if such changes do happen they often take far longer to have a major impact on society than originally predicted (although the corollary is that when

they do arrive such changes are often far more profound and far-reaching than first predicted.)

However, given the rapidly accelerating nature of today's technological progress, it is certainly not unreasonable to suggest that inter-communicating fully robotic cars that are able to safely navigate public roads unsupervised will be a reality by 2020 (although they won't be widely deployed by that date).

It's also highly likely that within a decade electric cars will have batteries that can power family vehicles for 500 miles on a single mains-supply charge[2] (and which can be recharged in a few minutes), while hydrogen-powered electric cars may be providing similar performance. Therefore many pundits predict that digitally-equipped, robotic electric vehicles made by a new set of "software-oriented" manufacturers are the near-term future of road transport.

But outside of a few clearly designated areas – inner cities, business parks, campuses, airports, etc. – fully autonomous cars will *not* make up the majority of vehicles on public roads before the year 2030. The unsupervised robotic cars that are then in use in such controlled areas will serve as bus and taxi services for the general public, providing transport for non-drivers, the elderly and for those who cannot drive themselves. At night in such areas robotic vehicles with GPS, infrared vision and a range of all-weather cameras and sensors will deliver, collect, clean and service our communities tirelessly.

However, even this limited deployment of autonomous vehicles (AVs) will have a dramatic impact on our lives. Here's how Jerry Kaplan (a Fellow at the Artificial Intelligence Laboratory at Stanford University) enthusiastically describes this urban driverless-car future in his recent book *Humans Need Not Apply*[3]:

> Personal productivity will soar because you can do other things in the car besides driving. Auto insurance will become a thing of the past. You can party all night at your local bar without risking your life to get home. The pizza delivery guy will become a mobile vending machine. Fantabulous!
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> Consider the economic effects of this on the typical family. According to the American Automobile Association (AAA), in 2013 the average car cost the owner $9,151 per year to drive fifteen thousand miles (including depreciation, gas, maintenance, and insurance, but not financing cost). But the average U.S. family has at least two cars, so that's about $ 18,000 a year. That works out to 60¢ per mile, compared to estimates of 15¢ a mile operating cost for shared autonomous vehicles.
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> So a typical family might see its cost of personal transportation drop by 75 percent, not to mention it will no longer need to pay or borrow all that cash to buy cars in the first place. That's a saving of nearly as much as a family currently spends on food, including eating out. How much extra spending money would you have if all your food were free?
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> According to a 2014 analysis in the MIT Technology Review, there's a "potential financial benefit to the U.S. on the order of more than $3 trillion per year." That's an incredible 19 percent of current GDP[1]. In short, this single application of AI technology changes everything. It alone will make us far richer, safer, and healthier. It will destroy existing jobs (taxi drivers, to name just one) and create new ones (commuter shared club-car concierges, for instance).

But despite such bold claims (perhaps over-claims) about the benefits of cars that drive themselves, it will be vehicles that are *semi*-autonomous which will be providing the main bulk of human transportation on most highways and public roads in the 2030s. Cars with a plethora of robotic driving aids which both protect and assist the driver but which still allow full human control of the vehicle whenever required are likely to be most peoples' choice of personal transport. Goods vehicles are also likely to remain semi-autonomous within this time frame (partly for reasons of load security).

There are several reasons why fully robotic cars won't have taken over from human-controlled vehicles in the next couple of decades. The first is that there are always a huge number of "legacy" vehicles in service. There will be hundreds of millions of older private cars on the road in 2030 and although

[1] Equal to the total annual amount spent on healthcare in the USA.

most of these will have some sensors, cameras and semi-autonomous safety features, it will not be cost-effective to retro-fit fully autonomous driving technology into older private vehicles.

Second, many members of the public will be slow to adjust to the idea that a fully robotic, unsupervised vehicle is completely safe at anything other than low inner-city speeds. Even when self-driving capabilities have been developed and perfected to the extent that legislators, regulators and insurers are happy to let speed-limited robot cars roam our public roads without a human in charge, large sections of the public may be much slower to become comfortable with the idea. A lack of public acceptance may delay the widespread adoption of robotic road transport (and public transport) for some years[2].

Third, fully autonomous vehicles must be made impervious to even the best and most determined hackers. This is a tall order, but the risks of vehicle control systems coming under criminal, malicious or mischievous control are so great that it must be made impossible (imagine a hacked car or truck travelling at high speed on a highway while holding its occupants hostage). Companies with their origins in software may be more expert at solving this hacking problem than traditional car makers.

Another reason for doubting the rapid ascendancy of fully robotic vehicles on highways is that even when it does become legal for autonomous cars to take to public roads, they will undoubtedly have to share road space with a majority of vehicles that are still controlled by humans (including motorcycles, bicycles,

[2] A catastrophic, well-publicised failure of autonomous-driving technology would have a huge impact on consumers' and lawmakers' attitudes and on adoption rates of autonomous vehicles. In such circumstances, it is likely that attitudes toward AVs would turn sharply negative and harden, setting back mass adoption of AVs by several years, if not decades.

etc). In this mixed environment it is likely that robotic cars will at first have to carry very conspicuous warning signs alerting other road users to their nature (perhaps a large illuminated letter “A” on their bodywork) in the way that in Britain the early horseless carriages had to be preceded by a pedestrian carrying a red flag to warn road users of the dangerous nature of the new-fangled automobile.

However, the main reason that the open roads of the 2020s will not be flooded with hacker-proof driverless robotic cars is that many human drivers will simply find them too annoying. By definition, robotic cars will drive precisely within the law and the Highway Code (or local driving statutes). They will drive themselves as if they are being driven by learner drivers. And, as every experienced human driver knows, being behind a vehicle driven in such a sedate manner is intensely frustrating. And frustration leads to unsafe driving and accidents.

Human drivers calculate legal and illegal risks every millisecond and for a large part of the time many impatient humans break the law repeatedly as they drive (or at least do not observe the regulations in their entirety). They frequently exceed the speed limit when they consider it safe to do so (and sometimes when it’s not), they regularly take chances, they drive where they’re not supposed to, they drive unaware of local speed restrictions, they anticipate traffic light changes, they cross lanes, cut corners and navigate around pedestrians and other road users at dangerously close quarters. For most of the time this is calculated “illegal” driving when is safe and traffic flows are improved as a result.

Although autonomous cars will be thousands of times faster at calculating risk than human drivers, they can’t be programmed to drive in such a constant risk-

taking fashion as humans. Common legal liability issues and the attitude of insurance companies would prohibit any robotic car taking to the road if its software caused it to drive in the way that most human drivers today control motorised vehicles.

And there are unique legal and ethical problems to be solved before autonomous vehicles are widely deployed (and these may need to be solved independently for each legal jurisdiction, and by each set of regulators). For example, should a driverless car swerve to save the life of the child who just chased his ball into the street at the risk of killing the elderly couple driving the other way? Should this calculation be different when it's the car owner's life that's at risk or the lives of his/her loved ones who are also in the vehicle?[4]

Even if we can codify our principles and beliefs in software, that won't solve the problem. Simply programming intelligent systems to obey rules isn't sufficient, because sometimes the right thing to do is to break those rules. Blindly obeying a posted speed limit of 60 miles an hour may be quite dangerous, for instance, if traffic is averaging 75, and you wouldn't want your self-driving car to strike a pedestrian rather than cross a solid double centreline.

For all of these reasons we can be sure that the first fully autonomous vehicles allowed onto public roads without a watchful, supervising human at the wheel will have to proceed very carefully indeed. And for these reasons human motorists are likely be driven mad by autonomous cars on the road as these vehicles will always proceed as if they're being driven by student drivers, like very elderly drivers or in the unnatural way adopted by police patrol vehicles when "setting an example". Frustration at this type of "over-cautious driving" is known to cause accidents as other drivers tailgate slower vehicles,

undertake, overtake dangerously and use other risky methods to escape being held up by the sedate progress that will necessarily adopted by fully robotic vehicles.

(It is possible, however, that the “frustration problem” that impatient human drivers will have with robotic vehicles will be worn down long before unsupervised robotic vehicles are allowed to take to the highways. The most advanced of today’s semi-autonomous cars include technology which automatically reads speed limit signs and intelligent cruise control systems which can be set to ensure that the vehicle always stays within local limits. Add-in systems which automatically warn following vehicles about tail-gating, automatically manage lane discipline and inter-vehicle distance and which capture and stream video images from 360-degrees around the vehicle, and vehicles which proceed as if on an un-ending driving test may become the norm long before the robots take over completely. At the same time there is likely to be an expansion of traffic management systems which control motorists’ average speed on highways. And insurance companies are already seeing the benefits of asking for “black boxes” to be fitted to vehicles driven by young or novice drivers. These black boxes report back on driving patterns and insurance premiums are adjusted to reflect perceived risk. In the near future we should expect to see insurers demanding black box monitoring of elderly drivers and, perhaps long before fully autonomous cars are on the road, many drivers who wish to benefit from lower insurance premiums will be driving under the supervision of a black box. Necessarily, such vehicles will also proceed more cautiously than do most drivers today. For all of these reasons, impatient drivers may have no choice but to get used to driving within the strict letter of the law.)

In the longer term (perhaps after 2035) all forms of road transport will be fully autonomous and all traffic flows will be controlled by a combination of computers within vehicles which communicate constantly with roadside sensors and local traffic control computers. (Vehicle-to-vehicle communication is known as "V2V", and vehicle-to-infrastructure communication is known as "V2X".) Road signs will broadcast their information (e.g. speed limits, dangerous bend ahead, etc.) and vehicles will have an entire "information map" about the road and traffic conditions that lie ahead of them.

Speeding and all types of risky driving routinely undertaken by human drivers will have become impossible and today's dangerous patterns of human driving will disappear as all traffic on all roads comes under computer control. This will necessarily involve a loss of personal freedoms for drivers who wish to drive themselves – and this restriction may delay the arrival of fully automated traffic flows still further. It will be a brave government that bans manual driving before the public absolutely demands it (but the allure of much lower insurance premiums may hasten that day).

Allowing for the necessary changes in legislation, automobile regulation, insurance company attitudes and public acceptance, I think the process will take over 20 years. In comparison, technology development is the easy bit.

Beyond 2035 or so, the only place where humans will be able to get behind the wheel and drive cars manually will be on specially-built driving circuits. Also, some nations in the world may keep certain highways available for manual driving as a "tourist attraction" (e.g. manual driving holidays in Dubai).

In this fully-autonomous transport scenario, overall traffic-flow will be speeded up, road capacity will be doubled, accidents will be almost completely

eliminated, and our models of vehicle usage will change[3]. But first we've got to get from here to there – from the point at which a few semi-autonomous features are just starting to appear in vehicles to the point where cars, trucks and buses can drive themselves across continents without a human in control.

In the interim, the way drivers think about "owning" a car has already begun to change. Fewer people buy cars outright, they prefer to rent or lease them, adopting a "subscriber model" of car "ownership" and, as new digital features appear more frequently in new vehicles, many drivers will regard them as they view their smartphones today; as an item that has to be traded in and up-graded every couple of years to allow access to useful or desirable new features. For a section of the population this means that they will be exchanging their cars for new models much more frequently. For those who can afford it, the car is becoming "a smartphone on wheels".

THE SEMI-AUTONOMOUS FUTURE

The assistance on offer from semi-robotic cars which communicate with each other and with the infrastructure around them will transform human driving and significantly improve safety in the immediate future.

The driving force behind the uptake of semi-autonomous technology by motoring consumers will be lower premiums offered by insurance companies, the opportunity to improve fuel economy and the increased personal safety provided by such vehicles. And some semi-autonomous driving aids are definitely "cool".

[3] Car-pooling apps such as BlaBlaCar are already enabling more people to make greater use of vehicles by automating lift giving. This type of service is likely to grow quickly and will disrupt bus and train providers.

Semi-autonomous features *already available* in private cars and commercial vehicles include hazard lights which flash automatically under hard braking (or when a vehicle is following too closely at higher speeds), front and rear distance parking sensors, front and rear cameras, blind-spot sensors and cameras (especially for commercial vehicles), additional internal air bags, external air bags (for pedestrians), rain-sensing automatic wipers, lane-wander driver alert, lane-wander auto-correction, automatic emergency proximity breaking (already reducing rear-end collisions), self-drive parallel parking, automatic road sign identification, automatic speed limit adherence, etc.

In the immediate future other semi-autonomous features appearing in vehicles will include highway autopilot (also known as "super cruise" – the car becomes fully autonomous when on motorways/freeways)[4], driver biometric monitoring alerts (a sound or vibration warns the driver of sleepiness, lack of attention, etc.), driver biometric monitoring and intervention (vehicle senses when driver becomes incapacitated – through heart attack, stroke, fit, etc. and which sends SOS and assumes control), head-up windscreen displays (including display of augmented reality information), cars which can drive themselves at slow speed within car parks, find a space, text its location and then return to the driver, 360-degree video recording at all time (for insurance purposes) and low-speed traffic-jam autopilot driving[5].

In the next decade cars will start to take over most of the mundane driving tasks and they'll greatly increase the safety of their occupants and other road users.

[4] Just available on Tesla automobiles

[5] As more semi-autonomous features appear in cars, will student drivers stop learning how to parallel park, or do three-point-turns? And will experienced drivers who have learned such things lose their skills?

THE FULLY AUTONOMOUS FUTURE

Eventually there will come a time when all vehicles on our roads are semi-autonomous, and many are fully autonomous. As mentioned earlier, it is likely to be in urban areas and controlled environments (campuses, airports, etc.) that fully autonomous unsupervised vehicles first appear in regular use. This isn't because it is easier for self-driving vehicles to navigate city streets – it's actually much more challenging. Fully automated highway driving is relatively easy for a robot vehicle (no cyclists, no pedestrians, no traffic lights, no children playing nearby, all traffic moving in the same direction, etc.) whilst equipping a vehicle to navigate busy shopping streets, school crossings, roundabouts, etc. is far more demanding. But vehicles on highways and open roads travel at dangerously high speeds and, if something should go wrong, the results would be catastrophic. So the autonomous driving future will start in built-up areas.

There will be millions of fully-autonomous vehicles navigating our city streets long before they're allowed out onto the highways. More than 50 percent of the world's population now live in cities and the reason we'll see fully robotic cars first in these great conurbations is because the speed at which vehicles travel in such environments is low. In cities autonomous vehicles are likely to be limited to a maximum of 20 or 25 MPH and they will be fitted with many defensive safety features designed to protect passengers, and to protect pedestrians and other road users in case of accident. These safety features will include dozens of airbags inside the vehicle, dozens of outward-facing air bags all around the vehicle and all of the sensors required for safe all-weather driving (including infra-red vision and a variety of radar/lidar systems).

Vehicles will also be able to receive information such as radar patterns, visual images and information about hazards from other vehicles in advance of them and so will be able to see the road a mile ahead and will be able to "see round corners". In addition, as the Internet of Things (IoT) begins to arrive all traffic signs will broadcast information and cyclists, pedestrians and all other types of road user will begin wearing garments which contain miniature location beacons which, by broadcasting their presence, will serve as radar identifiers to all other people and objects on the streets. Streets will be fully "mapped".

In addition to a plethora of sensors, fully automated vehicles designed to operate unsupervised will also need massive redundancy in their systems (every system must have an individual back-up system in case of failure). They will have redundant 360-degree cameras, redundant 360-degree radar, redundant computer systems, and a redundant motor to act as a failsafe. Because an urban ground environment is so much more complex to navigate than airspace, robotic cars will require 20 times more software code than is found in an average self-flying passenger jet aircraft.

Cities themselves will also have to change to accommodate and facilitate autonomous vehicles. Street layouts will be altered, sensors will be embedded in roads, lamp-posts and street furniture and pedestrian routes will need to be adjusted.

However, at the time of writing, only six percent of the US's largest cities include any language about self-driving vehicles in their long-range transportation plans. Most importantly, American cities don't yet have the land-use policies in place that will dictate where these cars can drive and if they must be separated (at first) from human-operated cars. And city administrators have not begun thinking in a future-forward way about

designing for the self-driving car society: building denser neighbourhoods, narrowing streets, and devoting much less real estate to parking[5].

However, when such vehicles finally become the majority mode of transport in inner cities, the benefits will be immense. As Jerry Kaplan further explains:

> This new technology is going to dramatically change the way we think about transportation, with an impact on society far greater than these words suggest. A better description would be "personal public transit."
>
> Why public? Once this technology becomes commonplace, there will be precious little reason to own a car at all. When you need one, you will simply call for it as you might for a taxi today, but it will appear much more reliably and promptly. (Most studies assume that the average wait in metropolitan areas would be around one to two minutes, including peak times.) When you disembark, it will quietly decamp to the nearest staging area to await a call from its next passenger.
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> Within a few decades, you will no more consider purchasing your own car than you would think today of buying a private railroad coach. The economic, social, and environmental consequences are difficult to overstate. Studies project that traffic accidents will fall by 90 percent. That would save in human lives the equivalent of ten 9/11 attacks annually in the United States alone. Vehicle accidents cause an additional 4 million injuries annually costing over $870 billion annually in the U.S. alone.
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> Then there's the concomitant savings in traffic law enforcement (cops on the road), wrecked cars, vehicle repairs, and traffic courts. Not to mention we will need only one vehicle for every three currently in use. And we're not talking centuries from now; the expert consensus is that 75 percent of the vehicles on the road will be self-driving in twenty to twenty-five years. This single innovation will transform the way we live.
>
> Garages will go the way of outhouses, and countless acres of valuable space wasted on parking lots will be repurposed, essentially manufacturing vast amounts of new real estate. Environmental pollution will be significantly reduced, along with the resultant health effects. Teens won't suffer the rite-of-passage of learning to drive. Traffic jams will be a quaint memory of more primitive times, not to mention that it may be possible to eliminate speed limits entirely, dramatically reducing commute time. This in turn will

> expand the distance you can live from your workplace, which will lower real estate prices.

Today, personal cars are, on average, used only 4 percent of the time they are kept by individuals (average personal mileage in the USA is 15,000, in Europe it is closer to 10,000). For 96 percent of the time cars are owned they are idle: parked and waiting. This is an appallingly wasteful use of the resources and capital tied up in private vehicles[6].

Actually these car usage numbers are a little misleading. As the vehicle owners must necessarily sleep for one third of their lives, vehicles are really only idle for 94 percent of the time their owners are available to use them. However, when fully autonomous cars are fully established and approved for use on all roads (probably not before 2040), vehicles will be available with internal black-out and sleeping facilities which will allow car owners to sleep as they are being driven to their destinations.

In my novel "Emergence" (published in 2000) I imagined how humans might actually behave in their automated cars in the year 2038. In the scene reproduced below it is the morning rush hour on the Santa Monica Freeway in Los Angeles:

> Despite State regulations that required a driver to remain available to resume control of a vehicle at all times in case of automatic control failure, some drivers had swung their big chairs away from the dashboard and steering wheel to attend business meetings

[6] When robo-taxis and car pooling are widely and cheaply available, will conventional taxis and car rentals become redundant or converge in a single-service concept? What shift will occur within the insurance business if auto accidents become a matter of product liability rather than personal liability? Will the potential for improved safety lead insurance providers to reward AV owners? How will the anticipated reduction in accidents affect downstream businesses, such as body repair shops, towing services, and legal services? Expected traffic benefits and a reduction in the total number of cars on the road resulting from increased car sharing could also reshape parking and infrastructure investments and produce much lower road-energy requirements.

> locally, on the East Coast, in Europe or in any location in any of the 14 longitudes and 12 time zones in which other humans were still awake.
>
> Many had resumed their social conversations and get-togethers via the networks, some reviewed news, sport or business information in their viewpers while others donned immersion helmets, turned up their ScentSims and wallowed in pornography. A minority simply ate, drank and watched TV in air-conditioned comfort.
>
> Others, caught in a global frenzy of the time, gambled their way to work.

You'll see from this short extract that 15 years ago I thought it likely that the fully autonomous vehicles of the mid-21st Century would still have steering wheels. I still think that's likely for autonomous vehicles authorised for highway travel although I am now sure that small pods designed for urban transport will not have any form of manual driving controls

In the future, robots will do our driving for us (but not quite yet).

Ends

[1] One of the United Nation's Sustainable Development Goals is to halve the number of road deaths by 2020. Road accidents kill more men than women, and are the biggest killer of 15- to 29-year olds globally. As well as the human toll, it is an economic burden, costing the global economy an estimated 3% of GDP, and up to 5% in the poor and middle-income countries where 90% of deaths occur but only half the world's vehicles are driven. (Source, The Economist)

[2] See http://www.ft.com/cms/s/0/149ca550-7e30-11e5-a1fe-567b37f80b64.html#axzz3q3JJxh00

[3] Humans Need Not Apply, Yale University Press, 2015

[4] https://www.bcgperspectives.com/content/articles/automotive-consumer-insight-revolution-drivers-seat-road-autonomous-vehicles/

[5] http://gizmodo.com/self-driving-cars-will-be-on-roads-by-2020-but-no-us-ci-1741556954