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Autonomous Vehicles: What Will the Future Look Like?

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The world is changing very rapidly. All economies, both advanced and emerging, are facing big demographic changes, with ever-increasing levels of automation and interconnectedness. One of the processes that are poised to have an enormous effect on society in general is the availability of mobility on demand.

This article examines the effects of mobility on demand provided by fully autonomous vehicles, corresponding to a level 5 automation according to the current SAE classification. These smart, efficient and interconnected vehicles will offer the possibility of pick-up on demand and drop-off at any desired location with a vehicle specifically chosen for that trip. This paper will focus both on personal and commercial transportation, with emphasis on personal transportation.

Recent studies suggest that fully autonomous vehicles have an outstanding potential in reducing pollution, lowering congestion rates, increasing the frequency of transport, making transportation cheaper and faster, and allowing for a complete redesign of the cities of today.

While these dramatic improvements are possible with current internal combustion engine vehicles, only with a transition to fully electric automatic vehicles and the use of vehicles of different sizes according to the type of trip the full potential of these improvements can be achieved. For example, small one-person vehicles might be used for work commutes, hatchbacks for groceries, minivans for family trips, and so forth.

While the future is still uncertain, it is likely that private ownership rates might drop in favour of on-demand automated cab-like transportation or mobility on demand. Private or public enterprises might operate fleets of vehicles, which will use techniques such as cameras, radars, GPS, internet and other advanced control systems to operate safely on the road, as demonstrated recently by pioneers such as Tesla Motors, and now expanded by many other manufactures, including leaders such as BMW, Ford and Volvo among others.

Keywords: autonomous vehicles, electric vehicles, mobility on demand, transportation

1 Introduction

All over the world automated systems are being developed and adopted ever faster. Virtually all sectors have seen the adoption of automation, most commonly in industry, but it is its use in the service sector that's booming.

Depending on how it is addressed, an increase in automation and interconnectedness might be both good or bad for human society. Advances in technology such as smart phones, data connectivity and fast data processing are paving the way to profound changes in the transport sector which are driven by rapidly changing social and cultural trends.

Mobility on demand refers to an integrated interconnected on-demand transport system with autonomous vehicles ferrying passengers from point A to point B. This fleet could either be composed of vehicles of various sizes, for example composed of small one-person vehicles for work commutes, hatchbacks for groceries, minivans for family trips, and so forth, or uniform vehicles, of the same shapes and size.

The aim of the paper is to provide an overview of a widespread adoption of such a system. This overview will not only apply to developed mature economies, which are for the most part OECD countries, but also developing ones. In this paper, we will focus both on personal and commercial transportation.

First, we will examine the importance of software-based automation and the effect it has on labor markets. Secondly, we will examine the probable outcome of a widespread adoption of autonomous vehicles, both positive and negative. We will conclude the paper with a suggestion on further studies.

2 Automation

Automation is one of the most important aspects of development. In the broadest sense automation is the execution of a function by a machine that was previously carried out by a person (Parasuraman & Riley 1997).

When thinking about automation, the usual association are factories filled with robots or machines doing repetitive tasks. Certainly, this is the only way automation has been used until recently. Automation however, has expanded drastically in all walks of life thanks to advances in computerization. Countless sectors have switched to some level of computer-based automation. It has been used in production of food, utensils, tourism, online shopping and increasingly in sophisticated tasks once reserved for humans.

Computers solve problems with algorithms, which are a set of rules to be followed (Huang *et al.* 2001). New algorithms are being developed which can recognize patterns from big amounts of data (see for example Gietelink *et al.* 2006) and can substitute human labor in a wide range of routine and non-routine cognitive tasks (Brynjolfsson & McAfee 2011). One of the surprising aspects of automation is the capability of computers to perform highly skilled tasks, even such as those made by managers, physicians or senior executives (Chui, Manyika & Miremadi 2015).

Recent groundbreaking development has seen computers that can also be programmed to learn autonomously from data and teach themselves (Bessen 2016; Rotman 2013). Therefore, it is now possible to have a vehicle with a computer and advanced sensory equipment, like radars, GPS and lasers, able to drive itself.
One early use of an automated system is the management of large investment portfolios, with computers using algorithms to constantly sift through data and find useful patterns (Lupien, McCormack & Schulman 1992). Other successful newer methods hail from the medical sector, with systems being used for tasks as diverse as acquiring micrographs and in general to emulate all decisions and actions of highly trained microscopists (Carragher *et al.* 2000) or systems used to monitor and deliver medication (Day & Ruchti 2017). Uses in transportation include automated identification systems for ships (Balduzzi, Pasta & Wilhoit 2014) or automated satellites to classify ice-water from space (Leigh, Wang & Clausi 2014). Also, we must mention the ever-expanding use of autonomous vehicles in warehouses to manage all goods stored inside (Wurman, D’Andrea & Mountz 2008).

3 Autonomous driving

The main requirement of modern industrial automation and production systems is to provide enough flexibility for automatic reconfiguration, able to respond promptly to changes in the environment and to users' demands (Mendes *et al.* 2009). Autonomous driving is quite a complex operation, with there a lot of tasks occuring simultaneously, such as environment perception, localization, vehicle operation, unpredictable traffic and planning (see for example Levinson *et al.* 2011; Frazzoli, Dahleh & Feron 2002; Buehler, Iagnemma & Singh 2009).

The leading organization involved in developing standards for autonomous vehicle operations is SAE International. It categorizes the levels of autonomy a vehicle possesses. There are 6 levels of autonomy ranging from 0, with no autonomy and total human control to 5, complete autonomy and no human control necessary (*SAE International J3016* 2014).

Almost all vehicles today fall in levels 0 – 2, with the driver fully in control of the vehicle and completely responsible for the driving. In case of faults (such as accidents or abnormal traffic conditions for example) the driver has less than a second to react, thus is not allowed to engage in other activities. Examples of a category 2 vehicle, the current most advanced option, includes adaptive cruise control, lane departure warning and traffic sign recognition.

The next level widely achieved will be level 3, where the driver doesn't need to constantly monitor the road but is required for occasional control with a comfortable transition time to active driving of several seconds (Politis *et al.* 2015). An example of such a vehicle is the Tesla Model 3, a mid-range competitively-priced sedan, which can function autonomously most of the time ('*Model 3*' n.d.). Such vehicles are impressive as they allow the driver to safely focus on other activities while driving, though for a short period of time.

For higher levels of automation, including 4 and 5, many to all complicated driving decisions and processes must be adopted by the vehicle. Reaction times for the driver increase further from a couple of minutes to being completely unnecessary, allowing the driver to freely engage in other activities, such as reading, working and even sleeping (Dokic, Müller & Meyer 2015).

Mobility on demand refers to an integrated interconnected on-demand system of autonomous vehicles that can transport users from one place to another at the push of a button.

3.1 Benefits

The first reason is that cars typically tend to be parked at least 90 percent of the time, even if both actual driving and all surrounding activities such as repairs, servicing, etc. are included (Mitchell, Borroni-Bird & Burns 2010). If only driving is included, that percentage jumps to 95 percent – for the US it translates to about 465 hour/year in the car (*US Department of Transportation* 2011).

The second reason is that all that time could be spent doing other more productive things, from work to sleep (Asgeirsdottir & Gylfi 2011). If we factor in sleeping, those 465 hours average to about 8 percent of wake time driving.

Finally, cars are expensive to own and maintain – in fact they can be one of the costliest things we own (Jackson & Marks 1999). With mobility on demand, those costs could be lower and be spread across a longer timeframe.

Proponents of mobility on demand point out the many benefits it would bring. For example, an increase in safety, as automation is safer and reduces human errors, which are the leading cause of traffic accidents. It has been argued that since humans are responsible for 90% of accidents, by changing to autonomous vehicles, about the same amount of them could be avoided (Fagnant & Kockelman 2015).

A reduction of the environmental impact is widely expected (Fagnant & Kockelman 2014). This is true especially with a switch from fossil fuels to electric engines can be expected. Even if all electricity needed came from coal plants, the total amount of pollution (and therefore negative externalities) would be lower than current fossil fuel use – let alone a switch to green methods of production and pollution at one source is easier to manage (Valeri et al. 2013). One of the biggest critiques to electric vehicles has been their limited autonomy, however some recent studies suggest that even big increases of autonomy don't lead to increases in the market share, rendering this argument somewhat mute (Valeri & Danielis 2015).

There isn't a need for all autonomous vehicles to be the same. A fleet owned by a taxi-like company could mostly be composed of small one-person vehicles for work commutes, hatchbacks for groceries, minivans for family trips and so on.

Other benefits include an increase in traffic efficiency and lower congestion rates, since automated vehicles could be interconnected and monitor each another's position, coordinating actions in a way that is impossible for human drivers, and an increase in convenience and productivity, since drivers wouldn't be involved in much or any of the driving being done (Spiegel *et al.* 2014). Autonomous vehicles could also relocate on their own to be closer to the next user with a faster arrival time and quicker overall service (Fagnant & Kockelman 2014).

Another potential benefit could be the emergence of widespread car sharing (Spiegel *et al.* 2014). Car-sharing services are growing worldwide and have many strengths, as well as some weaknesses, most notably the absence of one-way rentals. However, if the vehicles are autonomous, they could go back to a main station to wait for a next call, or even going to directly picking the next customer up, they would arguably be even more comfortable than private cars. Also, if vehicles were electric the station could also contain a charging installation, further improving the efficiency of the company (Spiegel *et al.* 2014).

Company-owned autonomous taxi-like services could be more appealing to many current drivers, as the cost of purchasing, maintaining, repairing and insuring of the vehicle could be spread across a large user-base, reducing the cost of personal mobility by leveraging economies of scale; it's simply a more economical and sustainable alternative than personal vehicle ownership (Chong *et al.* 2013).

Other authors have discovered other reasons to invest in mobility on demand. Spieser *et al.* (2014) for example argues that when returns on investment in existing technologies, such as road expansion, new bus services or subway lines begin to diminish, it is advisable to consider new solutions, such as mobility on demand.

Since this subject is relatively new, only recently have transportation officials at city, county or country level started exploring how autonomous vehicles will affect the urban environment, for example with new roadway design, parking costs and a different public transit (Fagnant and Kockelman 2013). A lot of the urban environment is meant and made for cars, so with fewer vehicles many roads and especially parking lots could be rebuilt in parks, stores, community centers and other uses (Grush 2016; Guerra 2015; Levinson 2015). Canada is actively planning for a future with autonomous vehicles and the implications they bring (*Preparing for Autonomous Vehicles in Canada* 2015).

Since autonomous vehicles are a newcomer in the transportation industry many people view them as potentially insecure (Fagnant & Kockelman 2015). As Parasuraman & Riley (1997) put it 'automation use (or lack of use) reflects perceived reliability'. However, this perception will most certainly be proved wrong. Current autonomous vehicles, like the Tesla, are indeed very save, at about the same rate as human drivers. We must stress however, that these vehicles are the very first breed of autonomous cars with relatively very few wide-ranging tests. Very soon, with software and sensor improvements autonomous vehicles will certainly achieve a much lower danger level. A lot of work is indeed being done regarding safely (Althoff *et al.* 2010). In fact, as we will discuss shortly, with greater reliability the emission of driving licenses might be faded out and insurance premiums will also inevitably plummet.

Other benefits include the inclusion of women in public life and business, a change already happening in the second demographic transition (Goldscheider, Bernhardt & Lappegart 2015). Some conservative countries have been slow to give equal rights to women, for example Saudi Arabia only allowed women to apply for driving licenses in 2017 (*Saudi women to be allowed driving licenses* 2017). Handicapped people could also benefit from this technology (Lozano-Perez 2012).

3.2 Issues

One of the biggest issues that autonomous vehicles face regards safety. There are two points that stand out. The easier problem concerns the reliability, or rather perceived reliability of such systems, as we have mentioned earlier. The other, arguably much more important point, concerns the ethics involved in these vehicles' accidents.

Many authors believe a traffic situation with solely traditional vehicles is relatively safe, one with solely autonomous vehicles is much safer, but one with a mix of both traditional and autonomous is potentially very unsafe (see for example Sivak and Schoettle 2015). The most common reasoning is that drivers and pedestrians start paying less attention if they know there is an autonomous vehicle driving around them, knowing that it is programmed to avoid them. We however disagree somewhat. We think this is mostly due to current test models, usually with obvious and noticeable sensors and systems protruding from the car. Normal commercial models of autonomous vehicles will certainly have hidden systems, such as the Tesla Model 3, for example. In short it would be impossible to tell the difference between a traditional and autonomous vehicle at a glimpse; let alone if this potentially autonomous vehicle is driven manually or autonomously unless there is physically nobody at the steering wheel.

Not all accidents can be avoided and crashes, both fatal and not, are going to happen. New kinds of regulation, especially in cases where harm cannot be avoided will have to be adopted and possibly conformed worldwide. Here, larger precocious nations that first adopt them might find that their laws are adopted by other countries.

It is important to adopt such systems as not to discourage potential buyers. Also, it is imperative to adopt 'moral' algorithms that will coincide with human moral attitudes, as to foster public acceptance to the use of autonomous vehicles. It is also important to avoid moral inconsistencies when trying to achieve both these goals simultaneously (Bonnefon, Shariff & Rahwan 2015).

A good example is given by Bonnefon, Shariff & Rahwan (2015) with three different traffic situations, which involve unavoidable harm. They imagine an autonomous vehicle driving on a road and an accident happens where:
a) the car can stay on course and kill several pedestrians, or swerve to a side and kill only one passer-by.
b) the car can stay on course and kill one pedestrian, or swerve to a side and kill its passenger.
c) the car can stay on course and kill several pedestrians, or swerve to a side and kill its passenger.

These are all ethically very difficult questions and represent a big obstacle to the adoption of autonomous vehicles that will have to be resolved (Deng 2015). The most common consensus is to adopt a utilitarian decision-making process, by which the best option is the one that results in the greatest common good for society (Greene 2014; Bonnefon, Shariff & Rahwan 2015).

One of the biggest commonly studied challenges of computer-based automation is job destruction (Arntz, Gregory & Zierahn 2016). Historically, automation and development would lead to better and often more numerous jobs. A prime example might be the invention of the automobile with the internal combustion engine. It created millions of jobs and literally transformed the world. Not only factory jobs for producing the cars, but also jobs in seemingly unrelated industries. Roads had to be constructed and maintained, traffic signals installed, there was a need for mechanic shops, roadside motels, restaurants, scenic routes, etc. With better mobility people started exploring previously difficult to reach locations and tourism boomed. Inevitably the oil industry boomed as well, with jobs from computing to engineering (Amatucci 2015). One relatively minor or simple innovation had a life-changing effect on the whole world. Recent studies suggest that, in developed economies, autonomous vehicles could cover most personal transportation needs with about 10% of the current private vehicle ownership rate (Spieser *et al.* 2014; Fagnant & Kockelman 2014; Pofuk 2017).

It appears however, that recently this paradigm has been broken. Today innovation and automation might end up destroying far more jobs than they create. A recent OECD analysis found that across the 21 OECD countries, on average, almost 1 in 10 jobs could already be automated (Arntz, Gregory & Zierahn 2016). The difference is that today computers can be programmed to learn autonomously from the vast amounts of data that they handle and teach themselves. The result is that we can perform many more tasks than before with far fewer people than before and as a result making many human jobs obsolete (Bessen 2016; Rotman 2013).

Since driving consists of a finite number of simple operations that can easily be codified, we are probably going to witness a loss of employment of millions of people who work in the transport industry – specifically, drivers. This might be the case with many other jobs (Bessen 2016). Companies can make huge savings by substituting drivers with computers. Instead of paying relatively high wages for the drivers on a weekly or monthly basis it will very soon be able to invest in a relatively higher upfront cost of automatizing trucks and lorries but incurring in low further costs (Sukkarieh 2000).

We conducted a survey in 2017 to determine 2 key aspects regarding the adoption of autonomous vehicles. The first one was to determine the size of the market – specifically, the number of people interested in using autonomous vehicles, referring to both privately and taxi-like company owned autonomous vehicles. The second question was to determine out of those who responded positively to the first question, the number of people interested in continued vehicle ownership as opposed to the sole use of an autonomous vehicle. Our results show that about 80% of respondents would consider using an autonomous vehicle, i.e. are not worried about its use. Regarding the second question, over a quarter of respondents stated that they would choose to use an autonomous vehicle while still retaining their own vehicle and the rest stated that they would only use a rented or mobility on demand autonomous vehicle (Pofuk 2017).

Incidentally this also means that in the near future, far fewer vehicles could be needed to provide the same level of transportation, which means car manufacturers will have to downscale significantly their production. This is an interesting subject, which has not been studied yet. Diminishing production will most likely cause increases of car prices, because of smaller economies of scale. This might be offset in the initial period by strong sales to developing economies, but even these might adopt said technologies very early on, the same way the mobile phones were adopted over traditional phones (see for example De Silva, Ratnadiwakara & Zainudeen 2009).

Autonomous systems appear to be very safe, with very low maintenance. Also, while there might be stringent laws regarding the number of hours worked for drivers, computers work without stop. For example, if limited to 8-hour daily shifts, a truck delivery from Spain to Finland might take 6 days for a human driver. An autonomous truck could complete it in about just 42 hours – less than 2 days. This translates to huge savings and increased competitiveness. For small local companies the investments might be too big or useless, however for larger international companies it could be very profitable. Given the extent of international trade, we expect this trend to increase even further.

Vandalism is potentially also a problem, as public transit vehicles and, to a lesser degree, taxis frequently require cleaning and repairing because of passengers littering, smoking, or spilling food or drinks. To minimize these risks self-driving vehicles might be furnished with hardened surfaces and electronic surveillance. Assuming such vehicles make 200 weekly trips, 5-15% of passengers litter causing $10-30 average cleanup costs, and 1-4% damage vehicles with $50-100 average repair costs, these costs would average between $200 and $1,700 per vehicle-week (Litman 2014).

If compared with conventional vehicles, autonomous vehicles in a taxi-like fleet will travel much greater distances within a given period and will wear out much sooner; this will however accelerate vehicle turnover times and the adoption of cleaner technologies (Fagnant & Kockelman 2014).

Also, it has been argued that since autonomous vehicles don't need human intervention in driving, people might opt to live in a favored neighborhood, but to have a longer commute (Ohnsman 2014). This would result in an increase of external costs such as congestion, less parking space and pollution emissions.

Also, we mustn't forget that cars not only provide mobility, but are also reflect social status, personal power, affection and recreation and leisure by themselves (Jackson & Marks 1999). Mobility on demand certainly isn't an answer to those needs.

Some researchers have suggested that pedestrians become less cautious and responsible around autonomous vehicles, which might lead to accidents or other related issues (see for example Millard-Ball 2016).

Autonomous driving raises the questions of insurance and liability as well. In case there is an accident, who will be responsible, the human driver or the car manufacturer (Douma & Palodichuk 2012)? Also, car insurance companies might need to change the way they operate, since with safer vehicles insurance premiums are poised to decline, which also translates to lower incomes for those companies. For example, in Europe alone there are 40.000 fatalities and 1.4 million injuries due to vehicle-related accidents every year (Gietelink *et al.* 2006). Car repair shops would also be affected with a much smaller volume of repairs, but this might be partially offset by the repair and maintenance of their technology.

We mustn't forget that for mobility on demand to be effective, we need to also have a system to exchange data between vehicles and the roadside infrastructure, so that they can effectively communicate among themselves (Antonelli & Chiaverini 2006; Cao *et al.* 2011). In Europe, some steps have been made in this direction, most notably with the introduction and standardization of a WIFI-based wireless system in 2015, offering ad hoc communication and message sets, along with management and security procedures (Festag 2014).

One last major problem is the predicted smaller need for professional drivers (Frey & Osborne 2017). In the US for example, more than 4 million people are employed in transportation and warehousing (*Employment Projections program* 2017). As many of these people are employed as professional drivers, over the next few decades they will slowly start to lose jobs to automated vehicles, contributing to a general rise in unemployment. It is even more pressing as advanced automation is rendering many other jobs obsolete as we have seen, and there are few new jobs on the horizon (Bessen 2016).

In conclusion, there are many benefits that the adoption of autonomous vehicles would bring. Several issues still need to be addressed, the most important ones relating to ethics, insurance and data protection and the social aspect of a growing number of people unemployed by machines. If these are addressed in a timely manner the transition should be relatively smooth, fast and efficient.

4 Conclusions

As we have seen, the development of sophisticated automated systems is booming all over the world. Most uses are in industry and production; however, it is its use in the service sector that is showing real innovation because computers are slowly being programmed to learn on their own. Computers are getting capable of developing algorithms to describe the way specific and often complex tasks function. This has virtually endless applications, including the control of autonomous vehicles.

Autonomous vehicles are ordinary cars capable of functioning completely on their own. Even though currently they have achieved a low level of automation, requiring human drivers to be present and always monitoring the functioning of the system, it is expected that within years these vehicles will be able to function completely autonomously, without any kind of human intervention. Mobility on demand refers to an integrated interconnected on-demand transport system with autonomous vehicles ferrying passengers from point A to point B.

A slow but steady shift is already on the way, with many companies and countries at the forefront of autonomous vehicles introduction. The beginning, like all beginnings is slow, but is poised to gain momentum as more work is done, data is collected and innovations arise and/or are proven.

Depending on how it is addressed, an increase in automation and interconnectedness in vehicles might create both problems or solutions. It is imperative that this is addressed worldwide in a timely manner to create a unified system of laws and practices. Benefits include savings, increased participation in business and public life, more freedom of movement, traffic efficiency, lower congestion rates, rise in safety, etc. This will encourage and speed up their adoption. Issues still to address include the fields of safety, insurance, liability, data exchange and infrastructure. It is undeniable though, that the future will look quite different from what it is now.

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