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REALITY OF AUTONOMOUS TRANSPORTATION TECHNOLOGIES IN GLOBAL SUPPLY CHAINS: THE CONSUMER DRIVEN DEMAND CHAIN

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ABSTRACT

Autonomous transportation has been implemented in supply chain for decades, especially in indoor environments, such as warehouses, where safety risks and regulations are less than in everyday traffic. Applications include horizontal and vertical transportation. Regarding outdoor transportation, the most used and researched application is platooning, which consists of a convoy of vehicles, where the first vehicle leads and the others copy its movements. However, full automation in this environment has not been completely achieved within this aspect. The paper aims to examine the important principles of autonomous vehicles, its applications, and the extent to which it impacts the transportation industry and global supply chains. Autonomous vehicles can perform driving functions by themselves, by sensing its environment and navigating with or without human input. The main autonomous functions can be divided in navigation, situational analysis, motion planning, and trajectory control. The benefits of this technology are improved safety, higher efficiency, lower environmental impacts and greater comfort, whereas barriers include laws and liabilities, high initial costs, ethics, human factors and security risks. The most important impact of autonomous transportation in supply chains is costs reductions, mainly due to staff reductions, fuel efficiency gains, accident savings and productivity gains. Through our research study, we examine the advantages of autonomous vehicles and how enterprises need to redefine their supply chains for ways to benefit from these new technologies and achieve competitive advantage in global demand driven markets.

Keywords: Autonomous Vehicles; Supply Chain Management; Transportation and Logistics; Cost efficiency; Demand Chain Management; Global Supply Chains

1. INTRODUCTION

Since the Industrial Revolution, the way of producing vehicles and its features started to change. Machines replaced hand manufacturing, and processes and transportation became more automated. New technologies and techniques have been developed for the automotive and transportation industries since then, to achieve today "what is probably the most disruptive period in their history since Henry Ford first developed the mass production assembly line back in 1908" [1]. New and cheaper software and sensors enabled the production and testing of vehicles that can drive without human input, called Autonomous Vehicles (AV), changing the way of moving people and things as we knew it, and producing great impacts on the way business models and logistical flows are handled.

From the first trials on unmanned vehicles, interest around the automation of transport increased, and multiple technology and automobile manufacturers have begun to invest in research and development of AVs [2]. Some important contributions have been made by

Volvo, Mercedes-Benz, Apple, Google and Uber. While years ago, self-driving cars were just a dream taken from futuristic movies, nowadays it is already possible to talk about it as a close reality [3]. Although vehicles without any human intervention are still in development and trial phases, most of the vehicles sold in the last years already have some degree of automation, such as parking assistance and cruising speed. Globalisation is making the transportation industry become more important each day, enhancing the need of transporting goods and people around the world. However, such growth in transportation solutions also increases the need for more people to drive vehicles, the costs to move cargo from one place to another and the negative impact on the environment, fueled by increasing CO^2 emissions [3]. In fact, the transportation industry accounts for more than a fifth of CO^2 emissions worldwide, mainly due to road freight transport [4]. Usually, transportation costs represent a huge percentage of a logistic company cost structure, depending on the mode of transportation. Considering the easily accessible and well-developed road infrastructure in almost every place of the world, “land logistics, i.e. rail and road transportation, link almost all logistics activities because even air and maritime transportation require some form of land transportation to reach the destination”. In fact, around 73% of inland cargo movement within the European Union is carried out by road [3]. The problem is that road transportation is one of the most expensive ways of moving cargo, which affects the companies’ economy.

The shortage of qualified drivers also affects logistic companies, not only due to aging population and truck drivers retiring, but also because the hours they are able to work are limited by laws and regulations. Moreover, road fatalities are an increasing concern. “The World Bank estimates that 1.5 million people die from the combined impact of air pollution and crashes worldwide each year” [4], caused mainly by human error, such as speeding, driver distraction, drunk, drugged or drowsy driving [5]. Following the developments achieved in the automotive industry, and with the rising interest on finding transport solutions, which are consistent, safe, efficient, more environmentally friendly and sustainable, but especially cost effective, the transport industry started looking for ways to adapt autonomous technology into trucks and heavier vehicles [6]. Since then, efforts in the logistic industry started to be driven towards AVs. With a modern customer willing to receive orders as quickly as possible, the introduction of self-driven vehicles is announced as a promise to reshape the mobility and transportation industry, as well as the whole supply chain management. However, some challenges must be overcome before full automation is possible, such as modifications in laws and regulations. Although implementation of AVs is gradually increasing, it is still unclear when businesses, governments and consumers will be ready for large-scale production [7]. The aim of this paper is to provide the background information necessary to fully understand the extent to which AVs can impact the transportation industry and supply chains. Basic technical concepts of automation will be addressed, as well as some current applications of this innovation. Considering that the technology is still in a trial phase, the outlook will be studied to understand how AVs are estimated to evolve in the next years.

2. LITERATURE REVIEW

According to NHTSA [5], an autonomous vehicle, also known as a driverless vehicle, self-driving vehicle, and unmanned vehicle, is a “combination of hardware and software (both remote and on-board) that performs a driving function, with or without a human actively monitoring the driving environment”. Under this definition, the vehicle is able of sensing its environment and navigating without human input, although it leaves open the opportunity for human intervention [8].

It is important to understand, however, that a unique self-driving equipment does not exist. As the NHSTA concept mentions, the ability of a vehicle to drive itself is rather the result of a combination of software and hardware, that together result in different autonomous capabilities, depending on how they are combined. According to DHL [9], the main autonomous functions can be divided in four: navigation, situational analysis, motion planning, and trajectory control. The navigation function basically creates a digital map with information on locations, road types and settings, terrain, and weather forecasts for route planning. Today this function is partially achieved by the Global Positioning System (GPS). However, in more automated vehicles, vehicle-to-vehicle (V2V) communication is added, which allows the exchange of information between vehicles. It is important, as technology evolves, to obtain updated digital maps, so as to facilitate the detection of lane closures, work zones, and other dynamic factors which can represent critical or dangerous situations [9]. This function monitors all the relevant objects and movements that surrounds the vehicle, using video cameras, radars and ultrasonic sensors. It can identify other vehicles, pedestrians, traffic signs and traffic lights. The difference between technologies used lies in the cost of installation and the fact that video cameras are limited in case of bad weather conditions, while radars and sensors create reliable images even in those situations, using electromagnetic and ultrasonic waves. More modern technologies include Radar (Radio detection and ranging) and Lidar (Light detection and ranging), both able to create virtual three-dimensional maps of the environment. While Radar uses radio waves to reflect objects and movements, Lidar emits ultraviolet light to recognize obstacles, and its size, location, relative distance, speed and direction [9]. They are usually used in conjunction, since although Lidar is more precise, Radar achieves greater visibility ranges [6].

In this function, sensors are used to monitor the vehicle's movements and ensure that it remain in its lane. The aim is to avoid collisions, working in conjunction with the navigation system and situational analysis. In this way, the correct direction is determined and monitored, as well as the static and dynamic objects in the surroundings [9]. The trajectory control function "manages the execution of pre-planned changes in speed and direction, while also observing and maintaining driving stability". Braking and accelerating actions that are performed by the autonomous system can cause loses of stability, which the trajectory control system needs to correct [9]. These four functions and technologies mentioned before are combined to create the autonomous functions that are already available in vehicles today. Although the technology already exists, the challenge is to identify and predict how the AVs environment would behave and establish the decisions the vehicle needs to make.

2.1 Automation Levels and Barriers

The NHTSA defined six levels of vehicle automation, based on the balance between vehicle and human control [7].

- *Level 0* - No autonomous intervention.
- *Level 1*- Some assistance is provided when either steering or braking/accelerating process.
- *Level 2* - The system can control both steering and braking/accelerating simultaneously. The rest of the driving and monitor task is performed by the human driver.
- *Level 3* - The system can perform all aspects of the driving task, although the human driver needs to be ready to take control in any circumstances.
- *Level 4* - The system is able to perform and control all aspects of the driving task, although the human driver needs to pay attention in some circumstances.
- *Level 5* - All the driving task is performed and control by the system. There is no need for the human to be involved with the driving task.

These six levels of autonomous vehicles can ease classification and also help decide the amount of technology necessary in the vehicles for each level [6]. According to DHL [9], around 90% of road traffic accidents are caused by human error. On the contrary, AVs are able to make decisions faster and without doubts. Furthermore, since the system is based on cameras, sensors and monitor technology, there is no place for judgements, as the possible ways to overcome obstacles in the roads are already programmed. In this way, AVs can drive "with more diligence, speed, and safety than human drivers", avoiding crashes and fatalities. In fact, autonomous features present in vehicles sold nowadays have already proved the improved safety, and full automation would be a solution for road accidents [7]. Considering safety driving would be improved, much of the costs invested in safety features in vehicles and routes would not be necessary any more, such as air bags, roll cages, guardrails and safety signs. Also, insurance costs should be lower than, as well as repair costs due to crashes would tend to disappear. Moreover, traffic congestion would be reduced due to lower road accidents, which account for around 25% of congestion [7].

Using navigation technology and V2V communication, AVs are able not only to know which are the busiest routes and choose alternative ways, but also to accelerate and brake according to other vehicles' movements. In this way, speed is more constant and fuel consumption is optimized. According to DHL [9], the use of AVs can save around 15% of motoring costs. What is more, since the system does not need to rest, unlike the human driver, costs reductions could reach 40% per kilometer when unnecessary stops are avoided. Another efficiency effect would be related to parking space, since much of this space is used inefficiently due to human errors. Furthermore, fully automated vehicles would be able to park for themselves out from the city center, allowing for the use of city center parking in more efficient ways [7]. Considering less fuel consumption due to higher efficiency, AVs environmental footprint is lower, achieving lower CO^2 emissions and 20-30% energy saving [3]. When fully automation is achieved, the driver would be able to pay attention to other activities, rather than the driving task, becoming in this way a passenger. "This also makes self-driving vehicles a very attractive form of transportation for the elderly, underage, people with physical disabilities, and even the intoxicated". Everything would be done by the system, from steering and braking, to parking and pick people or goods from specified places [9].

One of the major barriers for autonomous transportation is that, in most countries, self-driven vehicles are not allowed to move on public roads and highways. This is not just because it represents a new technology and the laws and regulations have not been modified yet, but because there are some problems that authorities need to solve first. On one hand, the infrastructure, such as highways, are not prepared for this kind of vehicles [3]. Also, although several countries are entering the race to develop AVs, for which they are modifying their legislation in order to allow testing of self-driving vehicles, there are still barriers and difficulties in discussion, such as technical standards, safety design criteria and standards, privacy and usage requirements [7]. On the other hand, discussions need to be held regarding liability criteria, since it is not clear who should be responsible in case of an accident. Since the vehicles' occupants would not be paying attention to the road, and would not decide which route the vehicle chooses, they can't be blamed in case an accident occur. In this case, liability would shift to manufacturers and programmers. However, before fully automation is implemented, the responsibility would be shared, and the human driver would need to pay attention and be ready to take control of the vehicle in case the vehicle requires so. In such case, and considering that in the beginning there would be certain degree of technical failure, liability represents a significant obstacle, and could discourage the introduction of AVs [7]. For the first phase of AV implementation, high initial investments would be necessary, from new software, cameras and sensors in vehicles, to infrastructure modifications. Also, in the beginning maintenance costs would be high, due to few specialists and knowledge. "This could also represent a major concern for smaller transport firms, which might lack the necessary capital" [3].

As already mentioned, while humans need time and feel the pressure of having to take decisions when driving and face a difficult situation, AVs are preprogramed to take fast decisions. However, these decisions could affect lives and are questionable in court. In this case, it is not always clear which decision to take in case there is no safe option and the AV needs to choose between affecting the passenger's life or other vehicles occupants' lives. There are no right or wrong answers, which creates the need to debate with respect this kind of situations. On the other hand, although AVs should be programmed to strictly obey traffic laws and regulations, the degree of obedience should also lead to debate, in case the decision could affect the passenger's safety [7].

Like every new technology, there is a learning curve to overcome, not only in the technological environment, but also for the human operators. "These include negative acclimatization of human drivers because of misunderstanding of, misuse of or overreliance on the automation system, as well as inappropriate distraction from the driving task" [7]. Human drivers need to be trained in the first phase to be alert and take control of the vehicle when is needed, since the transfer of control would be the most important task to avoid accidents. Furthermore, human drivers are not easily replaceable, since they undertake other activities apart from driving, such as loading and document management. The way companies would manage these activities needs to be solved before the implementation of fully automated vehicles. However, replacing human drivers would imply a problem too, since many jobs in the automobile and transportation industries may disappear [7]. Considering that AVs are highly connected to each other and to other computerized systems, there is a risk of cyberattacks. Also, a lot of data is captured by the cameras and sensors and managed by the system, which creates the need to protect this data and develop privacy policies [7].

2.2 Historical Perspectives of Automotive Transportation

Although in 1478 Leonardo Da Vinci had already thought about self-driving vehicles, his vision only started to become real centuries later, when the Phantom Auto experiment started to test remote controlled cars in 1920. General Motors also pushed autonomous transportation development with the introduction of street embedded wires 30 years later, but the project was not commercially viable. It wasn't until 1980s when the idea was actually put into practice, when the EUREKA Prometheus project was launched [3], and Carnegie Mellon University developed a working self-driving vehicle, called the NAVLAB [6]. However, "the turning point in the development of AV technology, was the Grand Challenges organized by the US Defense Department's, Defense Advanced Research Project Agency (DARPA)". It started in 2004, and the vehicles had to complete a 150 miles self-driven road race. In a second phase, in 2007, the competition was in urban streets, with other vehicles to navigate with, and the vehicles needed to obey traffic laws [7]. But the main challenge for companies was to launch an autonomous car, which could be commercially developed. Many technological companies, vehicles manufacturers, universities and governments have been investing in research and development of autonomous vehicles for several years. From Tsukuba University in Japan [7], to the GATEway Project in UK [10]. One of the most successful and known trials were the ones started by Google in 2009, after they hired the winner of the second DARPA Challenge [7]. Currently, the company is called Waymo, and have achieved more than 4 million miles self-driven [11].

From that moment, interest started to rise towards autonomous transportation and its commercial development. Companies such as Apple, Baidu, IBM and Cisco have joined the race to create the first fully autonomous vehicle ready for mass consumption, and of course, the automobile industry could not stay behind. "Almost all big automobile manufacturers have declared themselves to be working on an AV, among them Audi, VW, Mercedes-Benz, BMW, Ford, GM, Nissan, Toyota, Volvo, Renault, Daimler and Tesla. Interesting from a logistics point of view is the fact that, amongst others, Volvo and Mercedes-Benz are not only working on autonomous cars, but also on autonomous trucks" [7]. However, fully automation has not yet been achieved, since there is always the need for some kind of human intervention or control [10].

2.3 Global Supply Chains

Transport is one of the most important elements within any supply chain, which allows cargo movements from the raw material manufacturer to the end customer. Consequently, the impact of autonomous transportation in supply chains would be great and would cover almost every aspect of it [3]. As shown in Figure 1., efforts are driven towards the implementation of autonomous technology in every stage of logistics in the supply chain, from warehousing and controlled outdoor logistics, to line haul transportation and last-mile deliveries, including airports and ports [9]. Although fully autonomous vehicles have not yet been commercially developed to navigate in roads or highways, the technology is already known and has been implemented for decades in supply chains, especially in closed environments and controlled outdoor operations.

Self-driving vehicles have been implemented in supply chain environments in a first instance mainly due to three reasons. Firstly, because many logistic operations are carried out in closed and controlled environments, such as warehouses, production plants or ports; where movements are less complex and less risky than in urban roads and highways. Secondly, in these environments, there are fewer laws and regulations, since most of them are private venues. This allows companies to obtain knowledge about AVs, in order to be ready for a future mass implementation in public environments. Also, liabilities are usually less harming when transporting goods, instead of people. Thirdly, considering that transport represents a significant percentage in most manufacturers' cost structure, the savings involved in the implementation of AVs in supply chains are of particular interest for companies [7].

Figure 1. Autonomous transportation throughout the supply chain [9]

Transportation within a supply chain is generally divided into indoor and outdoor transportation. Indoor transportations are "those that take place by moving goods and packing them within a firm's facilities". Outdoor transportations are defined by "loading, re-loading and unloading goods together with the actual transportation between different locations. It involves transportations between suppliers, customer and even a company's own departments if they are geographically dispersed" [6].

Indoor transportation

Indoor transportation, as already mentioned, refers to all cargo movements carried out inside the plant facilities. In this environment, self-driving vehicles are generally called Automated Guided Vehicles (AGV), described as "autonomous vehicles widely used to transport materials between workstations in flexible manufacturing systems and perform a variety of tasks that involve automation in industrial environments" [7]. The first AGV was launched in 1954 by Barrett Electronics Corporation. This vehicle used wires to guide itself and was firstly used in a grocery warehouse [7]. Most of the AGVs that followed used the same technology, improved just by the use of markers instead of wires, such as colored lines that cameras in the vehicle could recognize and follow. The problem is that this technology, apart from being expensive to install, allows the AGV to follow just a predefined route. This means that if the manufacturing process changes at some point, the whole system should be changed. What is more, most of these kind of AGVs stops when they find an obstacle, and don't continue its way until the obstacle is removed or the direction is changed manually [9]. Currently, developers found a way to solve this lack of flexibility by the incorporation of depth cameras, sensors and lasers on the AGVs, which are now capable of performing 360-degree environment scanning and capturing the environment to identify its position and navigate avoiding obstacles. They are able to recognize the route, obstacles, develop human-machine and machine- machine interactions and decide to choose better alternatives if needed. As a result, manufacturers and distributors are using these autonomous systems worldwide, mainly encouraged by cost savings due to flexibility [9]. "Compared to human operators, AGVs can achieve efficiency, productivity and accuracy gains as well as increased safety" [7].

Indoor Applications

There are mainly two kinds of AGVs. The first group is able to perform horizontal movements from A to B, and is usually used to move big volumes of cargo over long distances. On the other hand, the second group is capable to perform horizontal and vertical movements, which makes them useful to load and unload goods from and onto racks, stands and conveyors [7]. The main benefit of the second group is that is not only capable of transporting cargo, but also to perform handling and storage activities. One of the most useful applications of AGVs is assisted order picking. Considering that manual order picking can take a lot of time and effort, and even more if the cargo is not uniform regarding size and shapes, AGVs can make the process more efficient, ergonomic and fast. What is more, DHL [9] considers the possibility of a system capable of going for its own to the packing area when it is full, and another one replacing it in the task. Most of the functions described above are already available in the market and are changing the way warehouses are managed. For instance, the famous retailer, Amazon, uses an AGV to handle products and take it to a human picker [7]. In fact, more innovations are under way, which will make almost the whole process autonomous, achieving in this way cost savings, more efficient, safe and faster transportation processes.

Outdoor transportation

Although indoor transportation represents the perfect environment for AVs, the aim for the automotive and logistic industry is to bring self-driving vehicles "out of the security of controlled settings into the uncertain world of everyday traffic" [7]. One first step has been taken by the development of AVs in controlled outdoor environments such as harbors, airports and logistics courtyards. For a second step, efforts are now driven towards the development of autonomous vehicles for long haul transportation, and especially for the last mile transportation, where most costs are incurred. Although it is possible to think that controlled outdoor environments are almost the same as indoor environments, yards combine not only forklifts and the classic indoor vehicles, but also trucks that are loading or unloading cargo, and employees that are managing operations. As a result, maneuvering in this kind of environments can be even more difficult. AVs capable of performing yard logistics, such as maneuvering and repositioning pallets and swap bodies for themselves are very useful and can make these activities more efficient and safe [9]. Examples of these kind of environments are harbors, airports and logistic yards. However, considering the environment is similar, the same rules apply for liabilities, laws and regulation, and the ease of using these vehicles in private yards. Although similar technologies are used, since distances tend to be longer in outdoor environments, autonomous trucks are also used. One example of self-driving vehicles used in controlled outdoor environment can be found at the Container Terminal Altenwerder (CTA) in Hamburg harbor, where “container handling is almost completely automated. A total of 84 driverless vehicles transport containers between the wharf and the storage areas via the fastest possible routes. Navigation is performed using 19,000 transponders that are installed in the ground” [9], increasing in this way handling speed and efficiency. There is also a research project called SaLsa62, testing AVs in yards, by the installation of sensors which can identify vehicles, forklifts, and people, in order to achieve a safe and efficient navigation [7]. In this way, ports and airports are increasingly implementing Radar and Lidar in its operations [1]. The most important benefit of AVs in controlled outdoor environments is to reduce the costs of turnaround times, labor costs and lead times [7].

Non-controlled outdoor transportation can be divided in first mile, middle mile or line haul transportation and last mile. Line haul transportation is the longest, more predictable and less complex part of a truck’s journey, while the first and last miles are similar regarding required turns and traffic density in urban areas. As a result, the first step in AVs development are being taken for roads and highways, although the aim is to replicate achievements in the first and last mile, when developments reach a point of standardization [1].

Line haul transportation

In public roads and highways, the main risk to undertake is the probability of a road traffic accident. Lives and cargo are lost every year worldwide, and weather conditions and human error represents a risk even for experienced drivers. Moreover, trucks are heavier than usual vehicles and maneuvers are more difficult to perform. “Autonomous technology can help drivers to react faster to oncoming dangers and calculate the safest maneuver, taking into account the truck’s current status and the driving conditions” [9]. In fact, technology capable of maintaining safe driving distances and optimum speed, and applying emergency braking are already available in the market. Especially in long haul trucking, the main benefits of the implementation of AVs is the cost savings. For instance, in the US, driver wages account for more than 30% of the total shipping costs, and with AV mass development, the struggling of finding trained or experienced drivers and paying huge amounts of money for them would be solved [7]. One current example of AV in long haul transportation is being implemented by Suncor Energy in its oil sands operations. In fact, the company is willing to replace its entire fleet with AVs. It has been estimated that with 52 vehicles owned by the company, maintenance costs and fuel consumption decreased by 5% to 15%, while also achieving $10 million of labor costs savings per annum [8].

Platooning

Regarding long haul transportation, the technology that has come to revolutionize the industry and has been most developed in the last years is Platooning, also known as road trains. It refers basically to a formation of at least two vehicles, with the first one taking the lead and the others following it at very small distances from each other [7]. The technology is based in Radar, Cooperative Adaptive Cruise Control and V2V communications to control vehicles both longitudinally and laterally at highway speeds [12], and to allow them to navigate much closer than would be possible with human drivers [7]. As part of the Sartre Project, the first successful platooning on public roads was tested in Barcelona in 2012, Spain, using a lead Volvo truck, followed by 4 other vehicles. In this case, the driver provided steering, acceleration and braking function for all the vehicles in the convoy [9]. The aim of platoons is to improve safety, efficiency and congestion, mainly due to consistent speeds between vehicles [13]. However, the most important benefit for logistic companies and supply chains is the significant decrease in fuel costs, which can reach 15% savings [9]. Considering that, for instance, 10% of the US oil is used in long haul trucking, and that fuel represents 38% of a fleet operating expenses, significant cost savings could be achieved. A platoon test in 2013 showed economy improvements of around 4.5% for the lead truck and 10% for the following truck, when travelling at 100 mph at 11m spacing [12]. As a result of fuel savings, platooning also reduces the environmental footprint of trucks navigating on highways and roads. ***Platooning*** concept is most advantageous when travel speeds are higher, truck trips are longer and the likelihood of encountering similar trucks installed with this technology is high" [12]. The last mile in a supply chain, or last part of cargo transportation, is the one that needs to be overcome in order to reach retailers or end customers. This is seen as a challenge for every supply chain, since it is usually the less efficient and most difficult part [7]. The original cargo is divided in smaller deliveries, which need to be transported to different locations, as shown in Figure 2. , where the cargo deconsolidates to be delivered on a product level, and economies of scale reached by long haul transportation disappear [6].

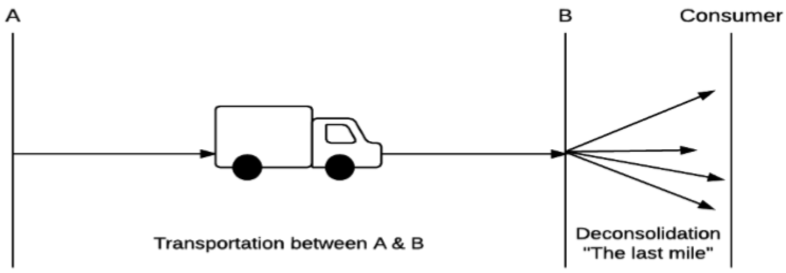

Figure 2. Last mile deconsolidation

The problem with the last mile delivery is that usually, delivery locations are in cities, which makes it necessary for logistic companies to enter the environment of everyday traffic, which is more complex and dynamic than roads or highways. Urban areas are congested, both of people and many kind of vehicles, and are consequently less predictable, as everyone moves in different ways and at different speeds [9]. This makes the last mile delivery much more expensive that the transportation of the consolidated cargo, and can generate negative impact in the companies' profitability [6]. However, the urban environment not only represents a threaten for self-driving development, it also represents an opportunity, since speed limits are lower and there is more time for the system to identify its environment and surrounding objects in order to take better decisions [9]. In fact, AVs would represent an enormous advantage for logistic firms and supply chains when higher levels of automation are achieved; if they are able to solve the last mile problem, transportation costs would be significantly reduced. Although there is yet no solution, many companies are thinking and doing research about the best technology to implement, from self-driving parcels and autonomous grocery shopping [9], to drones capable of delivering products within minutes or hours of the order placement. In fact, Amazon already announced its intention to deliver orders with drones [14].

2.4 Impact and Outlook of Autonomous Transportation

It is easy to assume that, while autonomous transportation would have a positive impact in logistics, it would also carry benefits for retailers, customers and the society in general, due to shorter lead times, delivery times and better performance levels. Improving efficiency would imply a better quality/price relationship for customers [3]. Although the most important benefit for companies is the reduction in transportation costs, there are some other positive impacts to consider. On one hand, the shortage of truck drivers is an increasing concern in supply chains, mostly due to the number of hours they have to work, the fact that they are far from their homes, fatigue and safety risks of the job itself [9]. In fact, according to Clements &

Kockelman [2], there is currently a shortage of 25,000 truck drivers just in US. Autonomous transportation would represent more efficient use of truck drivers, and even the removal of most of them, since fewer drivers would be necessary to perform the same task, with less breaks and stress levels [3]. Human drivers would now become "transport managers", and would be able to perform administrative tasks while the truck drives itself [12]. "In such a scenario, the cost per truck driver would increase, the number of hours of transportation per driver would increase, and the number of drivers would decrease" [2]. As a counterpart, the recruitment of qualified drivers as a competitive advantage will completely disappear, and the logistic industry would need other advantages to differentiate themselves from competitors [3]. What is more, millions of truck drivers would need new qualifications and new jobs. On the other hand, as long as some players would become irrelevant, new players are expected to become increasingly active, such as special service providers for the loading and unloading activities, document management, preventive maintenance and repair service providers and platoon service providers. These services would not be necessary for each vehicle separately, and could be managed remotely and on demand [3]. Furthermore, AV implementation would allow companies to know the exact location of vehicles and how much work they have performed without human intervention, which would reduce the necessary overall human administration [8]. Other benefit from the implementation of AVs in supply chains is that improved efficiency would lead to an increase in the capacity of transportation systems, mainly fueled by a reduction in traffic accidents and constant and coordinated navigation. Clements & Kockelman [2] claim that AVs "will cause a 22 percent increase in highway capacity at 50 percent market penetration, 50 percent capacity increase at 80 percent market penetration, and 80 percent increase at 100 percent market capacity". However, the ease for access to self-driving vehicles, especially for children, elderly and disabled people would increase the traffic and congestions, which could counteract and limit lane capacity gains [2].

As shown from research, in an environment where safety regulations limit the amount of time a human can operate a vehicle, the freight industry could save up to $168 billion annually by the introduction of self-driving vehicles, which are able to navigate 24/7. And as much as $70 billion of that figure would come from staff reductions [15]. Also, an estimated reduction of around 70% to 90% of traffic accidents [6], would lead to cost reductions related to decreases in the need of auto repair, medical, insurance and law industries [2]. Accident savings would account for $36 billion annually [15]. Furthermore, AVs could annually decrease the environmental footprint, by saving up to 300 million tons of CO^2 emissions by 2025 [6]. Taking into account the benefits of the development of AVs for mass consumption, as well as its challenges and counterparts, and considering that the technology is already being tested worldwide, the question shouldn't be whether self-driving vehicles will be available for mass consumption, but rather when they will be commercially introduced. In fact, most vehicles already hold this technology in any of its variants. "With nearly all large automobile manufactures and other powerful companies as Google working on their AV and governments investing in research projects, it is unlikely that the development of AVs will come to an end" [7].

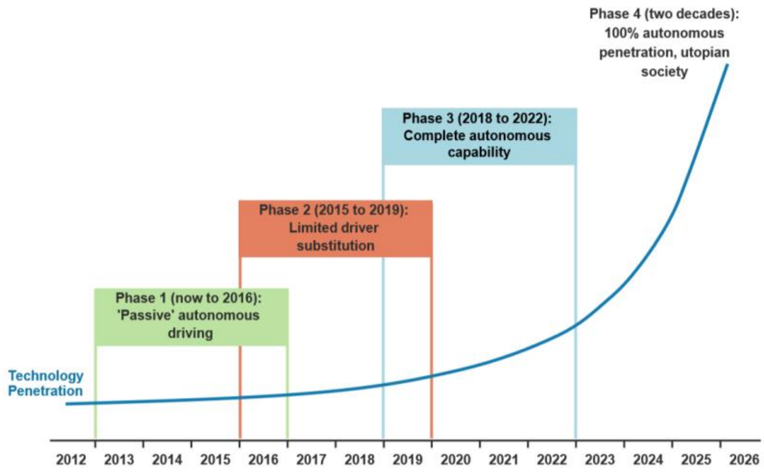

Figure 3. Adoption timeline for autonomous transportation technology [15]

Earlier in 2013, research analysts showed the adoption timeline (figure 4)), which identified four phases for the introduction of AVs for mass consumption [15].

1. *Phase I, Passive Autonomous Driving (2012 – 2016)*, is completed. It contemplates the introduction of technology such as adaptive cruise control, crash sensing and lane departure warning, with the aim to correct rather than control or perform driving tasks. This technology is present in most vehicles sold currently.
2. *Phase II, Limited Driver Substitution (2015 – 2019)*, is also almost completed, and contemplates the introduction of technology such as parking assistance. In this phase, the vehicle can perform some driving tasks, but the human driver is still the main performer of the driving task. Most of these features are present in vehicles entering the market today [7].
3. *Phase III, Complete Autonomous Capability (2018 – 2022)*, is currently starting. In this phase, the self-driving vehicle is capable of performing almost the whole driving task, but a human driver needs to be present in case there is a need for human intervention. Furthermore, some activities, such as merging into traffic, overtaking and leaving the highway will still be done by the human driver [9], although it would be allowed to relax during the rest of the journey [7].
4. *Phase IV, assumes 100% autonomous penetration of AV technology after 2025*. Although it is a utopic assumption, it is expected to be possible when barriers, such as liabilities and system programming ethics are solved [3]. In fact, Mercedes-Benz has already announced its Future Truck 2025 project, which aims to develop self-driving trucks by 2025 [7]. This will surely change the way logistics are held in every supply chain.

However, there is some skepticism within the industry regarding the need of human intervention in the transportation stage in supply chains. Some authors believe that it will always exist the need of a person at the time of the delivery [8]. According to McKinsey [16], some factors can contribute to the successfully development of autonomous transportation, which can be divided in company-specific and environmental factors.

Company specific factors:

- Define standards and protocols in order to achieve the necessary know-how and scale to make mass production of self-driving vehicles viable;
- Important research and development, as well as investments in new technology, such as sensors, artificial intelligence, and connected technologies, should be undertaken, as well as the necessary investments;

- Reach agreements between businesses, governments and consumers regarding data management obtained by autonomous technology, such as sensors and cameras, and the way they are going to be commercialized.

Environmental factors:

- Bring about the necessary changes to laws and regulations in order to allow companies to perform tests for the introduction of autonomous vehicles in everyday traffic, with real road conditions. Also, liabilities concerns need to be clarified, while allowing the non-human intervention;
- Ethics and human factors should be clarified for public acceptance and encouragement.

3. CONCLUSION

Self-driving vehicles have existed and have been implemented for years for transporting cargo and people, especially in supply chains, where cost savings are very significant. In the attempt to increase those savings by the implementation of autonomous vehicles, logistic companies have also achieved lead time, delivery time and CO^2 emissions reductions. Whereas indoor transportation has been the most popular and easiest way of implementing AVs in supply chains, considering that represents a more controlled environment and that rules and regulations are more flexible, efforts are being are will be focused on less controlled environments, such as roads and highways, with the final objective of addressing the last mile problem.

Although some degree of skepticism is valid regarding ethics and liabilities, as well as the need of a human driver for deliveries, the technical aspects for self-driving have been evolving fast, and predictions estimate fully autonomous vehicles to be a reality in less than a decade. According to this scenario, automation in the form of self-driving vehicles has the potential to change the way the whole logistic industry operates, as well as other industries, such as insurance and maintenance [16]. As a result, companies will need to redefine their supply chains and look for ways to take advantage of these new technologies and turn them to competitive advantages. Future research focus on incorporating case study research to examine the implications of technologies impacts on autonomous transportation methods within global supply chains to achieve new levels of optimisation and productivity .The concept will push global manufacturers to a new level of more technology enhanced autonomous systems and processes.

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