AUTONOMOUS VEHICLES: THE FUTURE OF AUTOMOBILES

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Abstract

Autonomous cars are the future smart cars anticipated to be driver less, efficient and crash avoiding ideal urban car of the future. To reach this goal automakers have started working in this area to realized the potential and solve the challenges currently in this area to reach the expected outcome. In this regard the first challenge would be to customize and imbibe existing technology in conventional vehicle to translate them to a near expected autonomous car. This transition of conventional vehicles into an autonomous vehicle by adopting and implementing different upcoming technologies is discussed in this paper. This includes the objectives of autonomous vehicles and their implementation difficulties. The paper also touches upon the existing standards for the same and compares the introduction of autonomous vehicles in Indian market in comparison to other markets. There after the acceptance approach in Indian market scenarios is discussed for autonomous vehicles.

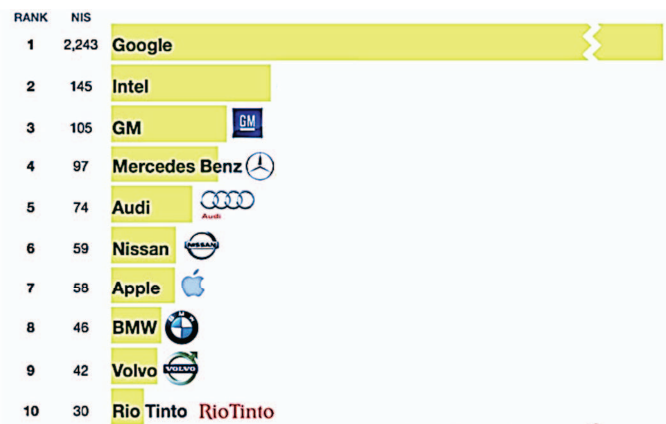

Figure 1: Most Influential Autonomous Cars Companies [18]

Keywords

Autonomous vehicle, RADAR, Sensors, Laser

Motivation

Millions of people have lost their lives or have become physically disabled worldwide in past many years as a consequence of traffic accidents. This has given the motivation to go for an Autonomous vehicle as almost most of the traffic accidents are caused by human mistakes. According to statistics, in the next 10 years the number of lives claimed by traffic accidents each year likely to be double. [15]

1. As per WHO about 1.24 million people die each year as a result of road traffic crashes. [16]
2. Road traffic injuries are the leading cause of death among young people, aged 15-29 years. [16]
3. Half of those dying on the world's roads are "vulnerable road users": pedestrians, cyclists and motorcyclists. [16]
4. Without action, road traffic crashes are predicted to result in the deaths of around 1.9 million people annually by 2020. [16]

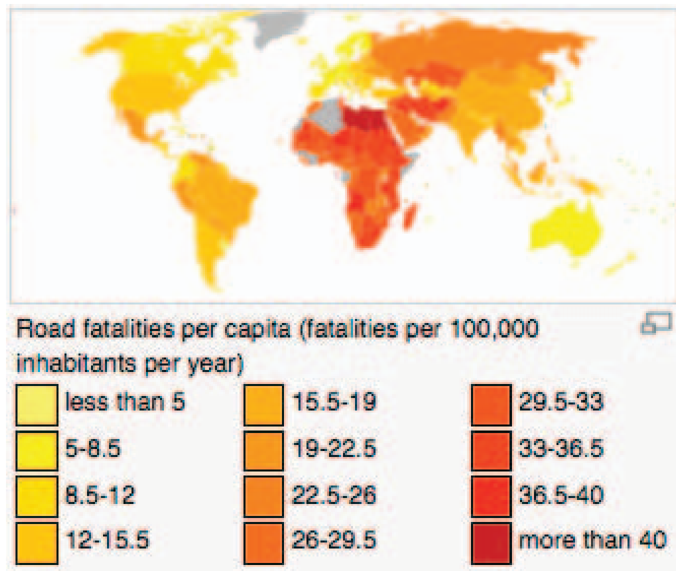

Figure 2: Road fatalities per capita (fatalities per 100,000 inhabitants per year). [17]

Introduction

A fully autonomous vehicle can be defined as a car which is able to perceive its environment, decide which route to take to its destination, and drive it. In other words we can say autonomous vehicles are smart cars or robocars which uses a variety of sensors, computer processors, and data bases such as maps to take over some or all of the functions of driving from human operators. Cars equipped with this technology will have its own benefits. It will likely reduce crashes, energy consumption, and considerably pollution. Recently major OEM's has announced their plans to begin selling such vehicles in a few years from now.

ROAD AHEAD	BMW	MERCEDES-BENZ	NISSAN	GOOGLE	GENERAL MOTORS
VEHICLE	5 SERIES	S 500 INTELLIGENT DRIVE RESEARCH VEHICLE	LEAF EV	PRIUS & LEXUS	CADILLAC SRX
KEY TECHNOLOGIES	Video camera tracks lane markings and reads road signs. Radar sensors detect objects ahead. Side laser scanners. Ultrasonic sensors. Differential GPS. Very accurate map	Stereo camera sees objects ahead in 3-D. Additional cameras read road signs and detect traffic lights. Short and long range radar. Infrared camera. Ultrasonic sensors.	Front and side radar. Camera. Front, rear and side laser scanners. Four wide angle cameras show the driver the car's surroundings.	LIDAR on the roof detects objects around the car in 3-D. Camera helps detect objects. Front and side radar. Inertial measuring unit tracks position. Wheel encoder tracks movement. Very accurate map.	Several laser sensors. Radar. Differential GPS. Cameras. Very accurate map.

Figure 3: OEM with ready prototype

Classification of Autonomous Vehicles

There are many OEM's which has already implemented this into their exiting production vehicles to come up with a prototype for testing purpose. This includes many renowned automakers. National Highway Traffic Safety Administration (NHTSA) has classified this technology into 4 different levels [3]:

Level 1- Function specific Automation:

This will include the automation of specific control functions, such as cruise control, lane guidance and automated parallel parking. Drivers are fully engaged and responsible for overall vehicle control (hands on the steering wheel and foot on the pedal at all times).

Level 2- Combined Function Automation:

This signifies the automation of multiple and integrated control functions, such as adaptive cruise control with lane centering. Drivers are responsible for monitoring the roadway and are expected to be available for control at all times, but under certain conditions can be disengaged from vehicle operation.

Level 3 -Limited Self-Driving Automation:

Drivers can cede all safety-critical functions under certain conditions and rely on the vehicle to monitor for changes in those conditions that will require transition back to driver control. Drivers are not expected to constantly monitor the roadway.

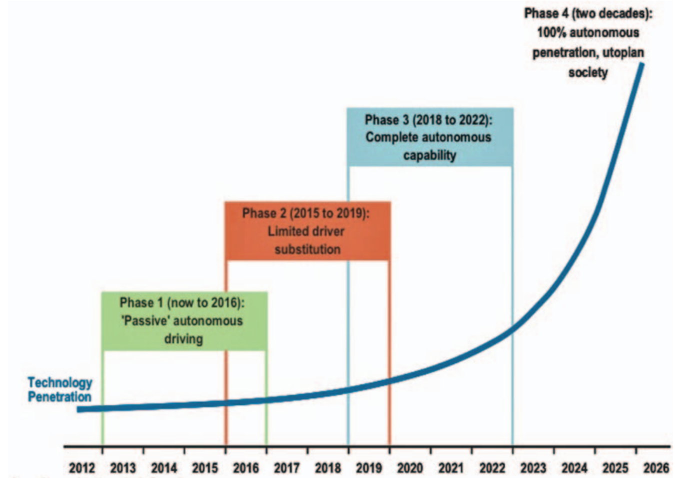

Figure 4: Timeline for Adoption (Morgan Stanley Research) [12]

Level 4 - Full Self-Driving Automation:

Vehicles can perform all driving functions and monitor roadway conditions for an entire trip, and so may operate with occupants who cannot drive and without human occupants. However many automakers have started testing there prototypes but still it's a long way to go to attain that accuracy and confidence where we can blindly put our faith on Autonomous vehicles. Google has set a target of 2018 to commercially launch its autonomous vehicle. Autonomous vehicles will have a long term impact on the society and it will be radical change on how we commute. But this change from conventional to autonomous vehicles should be a gradual one so that people will have that confidence and it can be used at large scale. There is a recent study done by Cisco on customer confidence on an autonomous vehicle. According to this study half of the world's consumer will trust a car which operates without a human driver. Cisco surveyed more than 1500 consumers around ten countries and focused on automobile buying and driving experience.

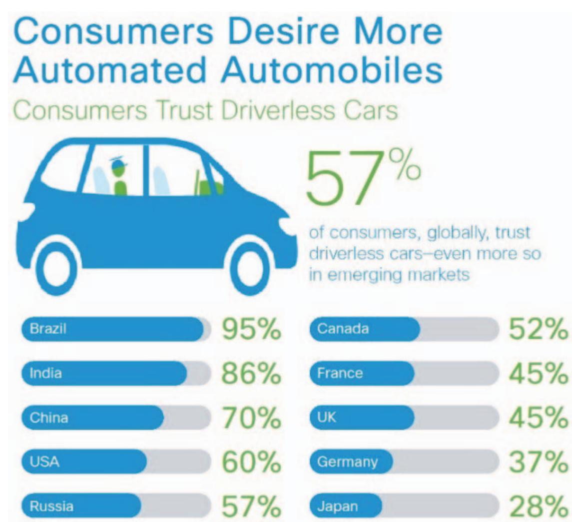

Figure 5: Cisco survey for Autonomous vehicles [5]

Objectives of Autonomous Vehicles:

In this section what are the main objectives of an autonomous vehicles have been discussed. The main objectives of an autonomous vehicle are listed below:

(a) Perception

(b) Motion Planning

(c) Navigation

(d) Behaviour

(a) Perception: It is the ability of the vehicle to understand its immediate environment. This will help the vehicle to avoid collision between vehicles and also to keep a check on any kind of obstacles which may come in the vehicle path. Now a days there are many electronic devices available in the market which can be used for this purpose. LIDAR, RADAR, GPS to name few. Light Detection and Ranging, or LIDAR, systems determine distance to obstacles by using laser range finders which emit light beams and calculate the time of flight until a reflection is returned by objects in the environment.

Similarly, Radio detection and ranging, more commonly known as RADAR is another key sensor for autonomous vehicles. Like LIDAR, RADAR systems uses signals time of flight to determine the range to objects in the environment. Unlike LIDAR, RADAR uses radio waves, which give radar systems different capabilities and limitations.

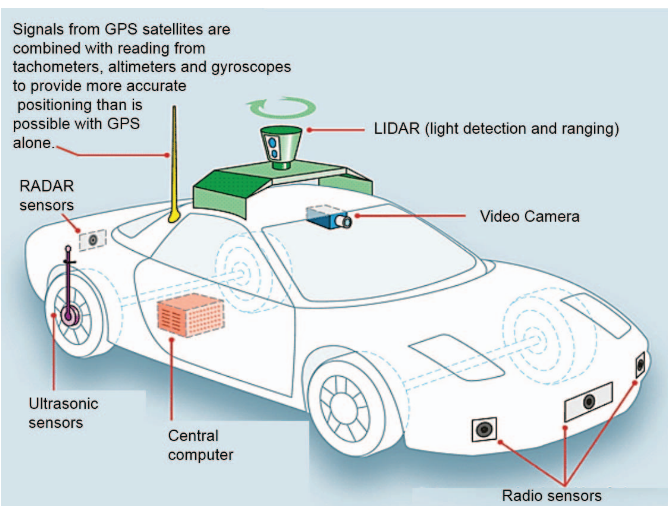

Figure 6: Perception devices (The Economist)

The other common device used in autonomous vehicle for perception is monovision cameras.

Monovision cameras means they have one source of vision. Monovision cameras are very simple devices and the video feed is usually used for understanding basic surroundings typically fixed infrastructure like lane markings, speed limit signs, etc. The hardware itself is pretty simple and cheap. Automotive monovision cameras are less sophisticated and have lower pixel density than cameras on smartphones.

(b) Motion Planning: Motion planning involves performing low level operations towards achieving high level goal. It's very complex to plan the path of an autonomous vehicle in a dynamic environment, especially when the vehicle is required to utilize its full capabilities. There have been recent advances in computational capabilities both in terms of hardware and algorithms and communication architectures which can help us in making an error free autonomous vehicle.

Motion planning consist of path variables which are to be controlled to avoid any kind of mishap. Those path variables are:

(i) Steering (direction): The motion planning should be efficient enough to steer the vehicle through any type of static or dynamic traffic.

(ii) Speed: Motion planning module should be efficient enough to control the speed of the vehicle according to the environment. After taking in account above mentioned parameters autonomous vehicle should be able to play with these parameters and generate local paths which can be followed.

It should also be able to assign costs to paths based on time taken, fuel consumption, distance from obstacles and other constraints. Once all the available paths are obtained it should choose the best path on the basis of time, cost, traffic and other various constraints.

(c) Navigation: Vehicles also use sensor suites for localization, i.e. determining their own position in the world. The use of global positioning systems (GPS) is essential for localization. Vehicle GPS systems receive signals from orbiting satellites to triangulate their global coordinates. These coordinates are cross-referenced with maps of the road network to enable vehicles to identify their position on roads.

Figure 7: Types of sensors and their location [13]

GPS is typically coupled with inertial navigation systems (INS) which consists of gyroscopes and accelerometers to continuously calculate position, orientation and velocity of the vehicle without need for external references.

(d) Behaviour: Once the vehicle has perceived its environment, completed the motion planning and navigated the route, it's time to act. So on the basis on all detailed parameters an autonomous vehicle takes decision. There are many challenges faced by an autonomous vehicle few of them are listed and discussed.

(i) Lane Analysis: In Vision based lane detection lots of methods have been presented in recent past. These methods use different lane patterns (dashed or solid), different lane model (2D or 3D, straight or curved, etc.) and also different techniques (Hough transform. Template matching, etc.). But till now autonomous vehicles have been only tested at roads which are well planned and structured. The capabilities of this vehicle on unstructured and unplanned road is yet to be tested.

Figure 8 shows an autonomous vehicle preparing to negotiate a curve in the road to reach its next destination. The optical image is overlaid with a proposed path of encircled destination points (white indicated that the lane marker detection and lane center estimation are functioning, and black indicates subsequent steps without current estimations), directional lines of motion to those points, and yellow lane and curb markers.

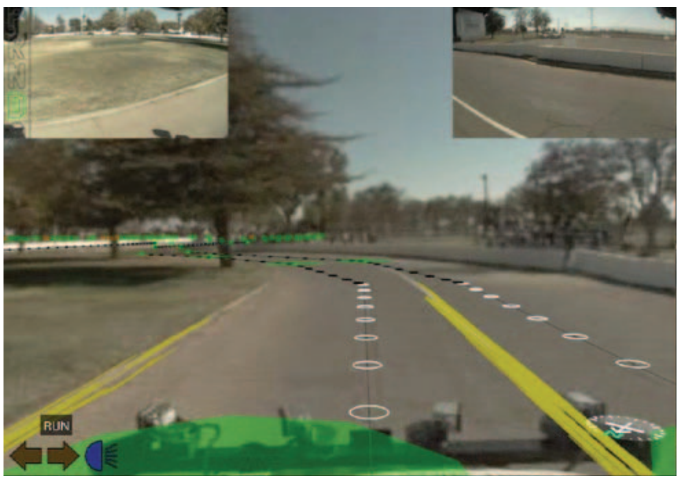

Figure 8: Lane detection (Lincoln Library, MIT) [7]

(ii) Overtaking: Overtaking has always been associated as the main cause of accidents worldwide. And in an autonomous vehicle the concern becomes more. Safe overtaking can be defined as vehicle crossing another vehicle safely well aware of vehicle coming from behind opposite direction.

Overtaking in autonomous vehicle is done by developing algorithms. In this there are electronics devices fitted in the vehicle which work on the logic given in the algorithm to complete this task. First the source car with the help of sensors detects the vehicle ahead and estimates the distance between them. With the help of this its estimates its relative speed. Stereo cameras are used to detect the moving objects which used edge detection technology. If during overtaking vehicle approaches from opposite the source vehicle detects and moves the vehicle to safe distance and supersede the decision of overtaking.

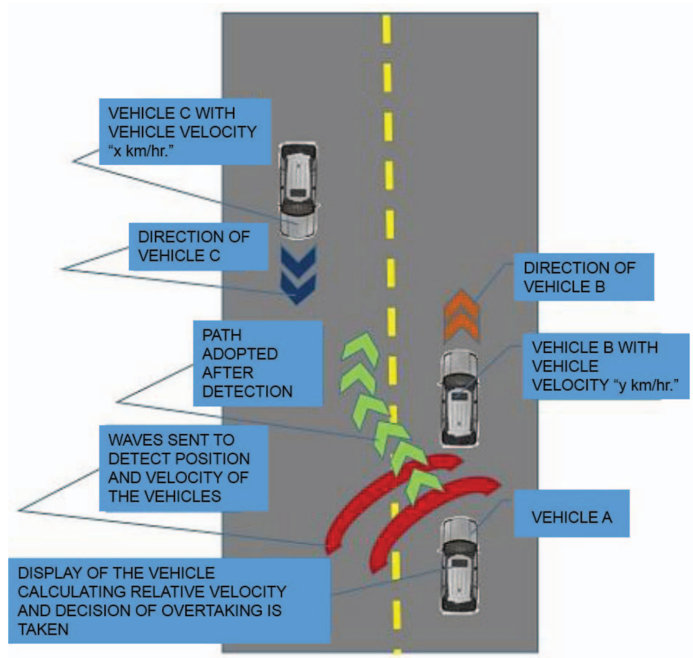

Figure 9: Schematic diagram of overtaking [8]

Barriers to Implementation:

Autonomous vehicles comes with lots of benefits such as reduced driver stress, mobility for non-drivers, increased safety, increased fuel efficiency and reduced pollution to name few. But still there will be many challenges which will act as barriers in implementation of this technology. Some of the major challenges are discussed ahead:

(a) Cost: The companies which are testing there autonomous vehicles have paid very hefty amount in building those vehicles. Google itself has paid around $80,000 for the AV module which is way out of a normal man's reach. It is expected once this technology is proven it may come down to half of the price which is still a very huge amount. In future if the prices of Autonomous vehicles comes somewhere near to conventional vehicles J.D power recent survey shows 37% people would definitely or probably but an autonomous vehicle as their next vehicle.

(b) Technology challenges: However many renowned automakers such Mercedes, BMW, Audi, Nissan have already announced that they will be ready with a partially autonomous vehicle (Level 3) but still it is a long way to go as in many countries road conditions are not up to mark. This technology still needs extensive research and testing to build that confidence where we can completely rely on these vehicles. According to experts it will still take another 10-15 years

(c) Removal of old cars: The foremost challenge for implementing autonomous car will be scraping of all the old cars which are not fitted with autonomous module because it cause of lot of unpredictable outcomes and so will reduce the effectiveness and safety of the autonomous vehicles. There can be a solution if the older cars can be retrofitted but again it is going to be a huge task by looking at the no. conventional vehicles plying at the roads. Also if everyone is ready to put into that much of cost.

(d) Unemployment issue: Although autonomous vehicles have many benefits but the biggest challenge we foresee is the unemployment issue. The day autonomous technology will be fully proven there won't be any need for drivers. So all those people who today earning their livelihood as professional drivers will no more be able to earn it. The most important industries which are supposed to be get affected with the introduction of autonomous vehicles are taxi, trucking and marine freighting.

(e) Security & Privacy concern: In today's world where everything is getting controlled by electronics security and privacy concerns is also a biggest issue. So do is the hackers. Electronic data is not safe today and it's vulnerable to information abuse. Even an autonomous vehicle can be utilized by any terrorist outfit to carry out their suicide missions. Also as these vehicles will be connected through GPS anyone can get the position and it can be used to any kind of bad purpose.

(f) Standards & Regulation: Government should make standards and laws to streamline the process of introducing autonomous vehicles into the road. There should be laws where the concern over privacy and protection and management of this huge private data should be addressed. Autonomous vehicles should not be used by any terrorist group this should also be addressed by government.

Some of the key characteristics of Autonomous Vehicle laws and regulations that have been enacted in US to date are listed below [2]:

1. **Nevada (NRS 482.A and NAC 482.A)**

   a. **Enacted:** June 2011, revised July 1, 2013.
   b. **Intent**: Testing, Individual ownership.
   c. **Technology certification facility:** Creates a privately operated technology certification facility market. Applicants to operate technology certification facilities must demonstrate the necessary knowledge and expertise to certify the safety of AV's pay a non-fundable fee of $300, and provide a surety bond or deposit of cash in lieu of the bond in the amount of $500,000.
   d. **Requirements of DMV:** The DMV was directed to draft and adopt regulations by March 1, 2012.
   e. **Insurance for testing:** Applicants for testing must pay a non-refundable fee of $100 along with a surety bond of $1 million for testing fewer than five AV's, 2$ million for six to nine, or 3$ million for ten or more.

2. **Florida (Fla. Stat. Title XXIII, Ch. 319, S 145)**

   a. **Enacted:** April 2012.
   b. **Intent:** Testing, development, and operation.
   c. **Requirements of DMV**: The DMV was required to prepare and submit a report relating to the safe operation of vehicles equipped with autonomous technology by February 12, 2014.
   d. **Insurance for testing:** Prior to the start of testing in the state, applicants must submit an instrument of insurance, surety bond, or proof of self-insurance acceptable to the department in the amount of $5 million.

3. **California (Cal. Veh. Code, Division 16.6)**

   a. **Enacted**: September 2012.
   b. **Intent:** Testing and operation.
   c. **Requirements of DMV:** Directs the DMV to draft and adopt regulations by January 2015.
   d. **Insurance for testing:** Prior to the start of testing in this state, the manufacturer performing the testing must obtain an instrument of insurance, surety bond, or proof of self-insurance in the amount of $5 million.

4. **Washington, D.C (L19-0278)**

   a. **Enacted:** January 2013
   b. **Intent:** Testing and operation.

Estimated cost savings and benefits:

It is not possible to anticipate the outcomes of the Autonomous vehicles as at this point of time they are in testing phase. But on the bases of assumption the impact by the Autonomous vehicles can be quantified in areas such as crash, congestion and other impacts.

	10%	50%	90%
Crash Cost Savings from AVs			
Lives Saved (per year)	1,100	9,600	21,700
Fewer Crashes	211,000	1,880,000	4,220,000
Economic Cost Savings	$5.5 B	$48.8 B	$109.7 B
Comprehensive Cost Savings	$17.7 B	$158.1 B	$355.4 B
Economic Cost Savings per AV	$430	$770	$960
Comprehensive Cost Savings per AV	$1,390	$2,480	$3,100
Congestion Benefits			
Travel Time Savings (M Hours)	756	1680	2772
Fuel Savings (M Gallons)	102	224	724
Total Savings	$16.8 B	$37.4 B	$63.0 B
Savings per AV	$1,320	$590	$550
Other AV Impacts			
Parking Savings	$3.2	$15.9	$28.7
Savings per AV	$250	$250	$250
VMT Increase	2.0%	7.5%	9.0%
Change in Total # Vehicles	-4.7%	-23.7%	-42.6%
Annual Savings: Economic Costs Only	$25.5 B	$102.2 B	$201.4 B
Annual Savings: Comprehensive Costs	$37.7 B	$211.5 B	$447.1 B
Annual Savings Per AV: Economic Costs Only	$2,000	$1,610	$1,670
Annual Savings Per AV: Comprehensive Costs	$2,960	$3,320	$3,900
Net Present Value of AV Benefits minus Added Purchase Price: Economic Costs Only	$5,210	$7,250	$10,390
Net Present Value of AV Benefits minus Added Purchase Price: Comprehensive Costs	$12,510	$20,250	$26,660
Assumptions			
Number of AVs Operating in U.S.	12.7 M	63.7 M	114.7 M
Crash Reduction Fraction per AV	0.5	0.75	0.9
Freeway Congestion Benefit (delay reduction)	15%	35%	60%
Arterial Congestion Benefit	5%	10%	15%
Fuel Savings	13%	18%	25%
Non-AV Following-Vehicle Fuel Efficiency Benefit (Freeway)	8%	13%	13%
VMT Increase per AV	20%	15%	10%
% of AVs Shared across Users	10%	10%	10%
Added Purchase Price for AV Capabilities	$10,000	$5,000	$3,000
Discount Rate	10%	10%	10%
Vehicle Lifetime (years)	15	15	15

Figure 10: Estimates of annual economic benefits from AV's in US [14]

Figure 10 shows the analysis done to understand the impact of three AV market penetration shares: 10 percent, 50 percent and 90 percent. Multiple assumptions are also taken in consideration which are mentioned in the above figure 10.

Benefits

Reduced driver stress. Reduce the stress of driving and allow motorists to rest and work while traveling.

Reduced driver costs. Reduce costs of paid drivers for taxis and commercial transport.

Mobility for non-drivers. Provide independent mobility for non-drivers, and therefore reduce the need for motorists to chauffeur non-drivers, and to subsidize public transit.

Increased safety. May reduce many common accident risks and therefore crash costs and insurance premiums. May reduce high-risk driving, such as when impaired.

Increased road capacity, reduced costs. May allow platooning (vehicle groups traveling close together), narrower lanes, and reduced intersection stops, reducing congestion and roadway costs.

More efficient parking, reduced costs. Can drop off passengers and find a parking space, increasing motorist convenience and reducing total parking costs.

Increase fuel efficiency and reduce pollution. May increase fuel efficiency and reduce pollution emissions.

Supports shared vehicles. Could facilitate carsharing (vehicle rental services that substitute for personal vehicle ownership), which can provide various savings.

Figure 11: Benefits from Autonomous Vehicles [1]

Conclusion:

There seems to be a lot of potential for autonomous vehicles be it transport or research. But the key lies in the safe implementation of this technology. And safe implementation can only be done by applying stringent rules and standards. As it takes a lot of time for people to trust a completely new technology and one single accident can completely bring down the reputation of this industry. On the other hand this technology will be very handy in solving many traffic related problems such as parking and traffic congestion, accidents by considerably reducing the travel stress. For military purpose autonomous vehicles can be a boon. It can considerably reduce the casualty, can play vital role in search operations, clearing mines and providing supplies to troops.

With increase in electronics and computerization of the vehicles there are more concern of cyber-attacks. There should be proper fail safe plans if the vehicles is lost from the grid or connection is lost with the controller. Keeping the high cost of sensors and equipment's used in Autonomous vehicles more research should be done to introduce new technologies by which this cost can be brought down. This can also be a big challenge.

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Definitions/Abbreviations

NHTSA	National Highway Traffic Safety Administration
GM	General Motors
RADAR	Radio detection and ranging
LIDAR	Light Detection and Ranging
GPS	Global Positioning System
INS	Inertial Navigation System
DMV	Department of Motor Vehicles
AV	Autonomous Vehicle

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