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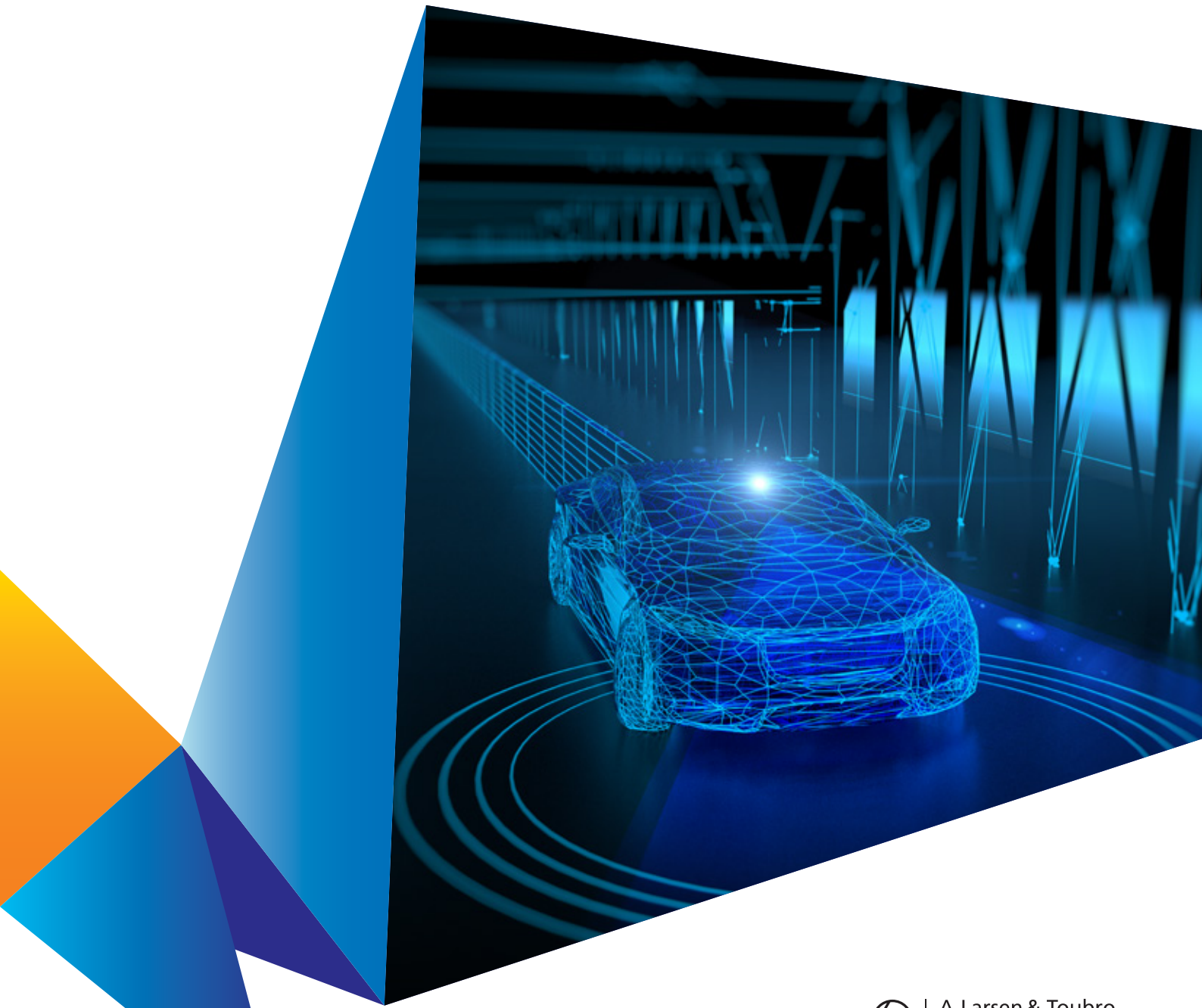
Whitepaper

Autonomous Vehicle: Hype to Reality

Author : Manabendra Mukherjee



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Executive Summary

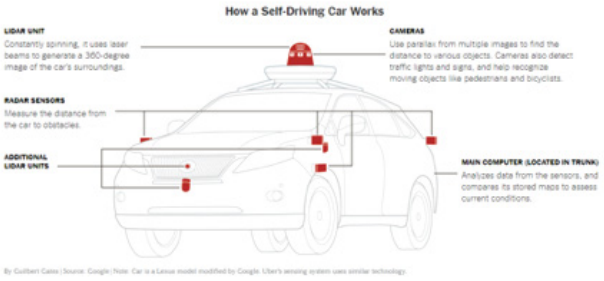
Autonomous Vehicles are expected to introduce an unmatched level of safety and comfort while keeping us mobile at the same time. This paper attempts to capture the shaping up of this very nascent and niche market from various perspectives. As Automakers and Technology firms rush to capture a pie in the lucrative upcoming market, technological challenges abound especially on fringe conditions that still require considerable cognitive abilities yet to be perfected by technology. Nevertheless, Automakers, Technology firms and ride-hailing services are collaborating and cross-leveraging strengths to rapidly come up the maturity curve and enter the lucrative automated ride-hailing market. Acquisitions and strategic partnerships, alongside individual competency are building abound. The key to succeed in the technology area would be intellectual property, and firms have begun claiming patents in this space to create an entry barrier. Traditional auto manufacturers may not define the potential future Auto market leadership as we see it today. Even if they remain, they would have evolved to a more technology enterprise. Decades of investment in developing, autonomous technology ensures that it may not be available for retail or private consumption on an immediate basis; however, the key to profitability and cost efficiency would perhaps be ride-hailing and mass transport.

Introduction

Automobiles are around for over a century now. For all the speed, agility and comfort that they have endowed us with, road accidents and fatalities have been an inseparable down side. According to National Highway Traffic Safety Administration (NHTSA), in the year 2016, an estimated 37,806 people lost their lives in Traffic accidents in the US alone, and another estimated 37,133 in 2017. In 94% cases, the leading causes were human errors like failure to buckle up, speeding, drunken-driving and distracted driving. A slew of law enforcement and educative measures seem to have reduced, however, could not eliminate traffic incidents entirely. The major plank behind the push for Autonomous Vehicle is to reduce road fatalities by eliminating the human errors at least in daily commute under regular driving conditions.

Since late 20th Century, efforts were in place to make vehicles self-driven, although military applications drove the funding for those studies. As early as 1920s, Tsukuba Mechanical Engineering Lab (Japan) developed a prototype that could track white lane markers and achieve up to 30 kmph (19 mph) speed. In the 1980s, Carnegie Melan University's NavLab and ALV projects started working on autonomous vehicle funded by Defense Advanced Research Projects Agency (DARPA). By 1985, self-driving prototype could reach 31 kmph/19 mph speed and by 1986, it could avoid obstacles. By 1987 it could drive off-road in day and night condition. After 2005, BMW entered into the fray. Google's Self-driving project began in 2009. By 2013, there was a huge interest in Autonomous vehicle as GM, Ford, Mercedes Benz, Toyota, Nissan, Audi, Volvo etc entered into the fray.

Today, the automotive industry is reaching an inflection point as we move from Advanced Driver Assistance System (ADAS) to the level of truly autonomous vehicles. Until recently, the approach to greater autonomy has been to ensure additional functionality through distributed, yet connected, Electronic Control Modules (ECUs) and cameras. However, the technology is maturing to include a greater variety of Hardware and complicated System development. As an example, Waymo (Google's Autonomous Car Business) deploys a



slew of sophisticated LIDAR, RADAR, Cameras and computing units to continuously monitor the surroundings and take split second decisions while driving without human interventions.

Levels of Autonomy

Level	Autonomous Capability	Human Involvement	Example
0-No Automation	None to fixed speed cruise control	Complete driving responsibility	 2018 Honda Fit
1-Driver Assistance	Can control either Steering or Brake/Accelerator under certain condition; has at least one Advanced Driver Assistance System (ADAS) features like Adaptive Cruise Control or Lane keep Assist	Complete situational awareness and driving control.	 2018 Honda HRV
2-Partial Automation	Can control both Steering and Brake/Accelerator under certain condition; has at least two or more ADAS features like adaptive cruise control, active lane-keep assist, emergency braking	Must monitor driving condition and take over immediately if condition exceeds system capability.	 Tesla Autopilot
3-Conditional Automation	Fully Control of vehicle under certain operating conditions like, freeway driving only	Driver need not monitor, but should be ready to take control of vehicle at all time with notice	 2019 Audi A8 (Traffic Jam Pilot is not offered in USA)

Level	Autonomous Capability	Human Involvement	Example
4-High Automation	Capable of performing all of vehicle driving (Steering, braking, accelerating, determine lane change, turn and use signal), respond to event and monitor environment. Could be limited to operate within a Geo-fenced area.	Driver may need to manage city driving and bad weather conditions	 Google's FireFly Pod car (Now defunct)
5-Full Automation	Capable of handling complete driverless operations under all conditions without geographic constraints. No longer, need Steering, Accelerator or other controls.	Passenger may enter destination and request emergency stoppage.	 Waymo owned Chrysler Pacifica

Key success factors in a nascent market

Autonomous vehicles are expected to establish a completely different market in themselves. According to Allied Market Research, Autonomous vehicle market would be worth USD 556.67 billion in 2026 from USD 54.23 Billion in 2019 at a CAGR of approx. 40%. Europe is estimated to be the growth leader with 42.6% CAGR between 2019 and 2026. However, this exponential growth rate would depend on multiple success factors listed below:

Enhanced Safety and traffic congestion concerns

Primary growth driver for Autonomous vehicle is safety buttressed by statistics of casualty prevention. This will unlock a potential new segment of users with age or physical disability as a barrier, who would be embracing a safe and cost-efficient mode of mobility. From Traffic administration and regulatory point, a low probability of collision would allow smoother traffic operation, higher speed of mobility and optimized traffic infrastructure management.

Demand for connected cars and growth in IoT infrastructure

Autonomous cars would have an even greater demand for connectivity over emerging 5G network. Intel estimates that self-driving cars may generate more than 4TB of data every day. Most of this data would be used to manage real-time dynamic GPS and vehicle to everything (v2X) communication. Low latency and high bandwidth 5G network could be key factors in wide spread growth of the autonomous vehicle market.

Demand for connected cars and growth in IoT infrastructure

Autonomous car will add directly to the bottom line of the ride-hailing services or fleet operators due to relatively low operating cost. As a result, lack of incentive in vehicle ownership, together with widespread growth of cost-efficient, ride-hailing services, is expected cause a significant shift in vehicle demand and prevalence of mobility-as-a-service.

Cost of Components and Manufacturing

Key components for autonomous system (LIDAR, Radar, AI Software, sensors, processors, etc) are expensive and have limited manufacturing base. For example, currently Velodyne, Luminar, AEye, Ouster, Blackmore are prominent LIDAR manufacturers with single unit cost of high end LIDAR ranging from USD 20,000 – USD 75,000. Mass adoption and innovation is expected to rapidly bring down the cost of components and would be a key driver in affordable autonomous vehicle.

Government Regulations

Government regulations and legal framework around autonomous vehicle are expected to pave the road for introduction of autonomous cars on the road. According to Mary Barra, CEO of General Motors –"The SELF DRIVE Act, passed by the House of Representatives, and the AV START Act, pending in the Senate, would direct the National Highway Traffic Safety Administration to issue new and revised safety regulations on an expedited basis. The bills would allow safe self-driving deployment during the period between enactment and NHTSA's issuance of new regulations, but only by manufacturers that prove their self-driving cars are as safe as human drivers."

Trials and tribulations of developing a self-driving car

On March 1, 2019, a Tesla Model 3 was involved in a fatal crash in Florida that resulted in death of the driver . It is presumed that the car was probably set on Autopilot mode. This is reminiscent of a similar fatal crash of Tesla Model S in 2016 set in autopilot mode.

Autonomous cars have generated a great amount of public interest over the years. Drive- assist features including Lane departure, adaptive cruise control, collision prevention, blind spot detection. etc have significantly enhanced the safety capabilities. However, over a decade of focused development and billions of dollar worth of investments have not yet resulted in large-scale adoption of a fully autonomous technology. It seems developing the core self-driving technology could not be as complex as adopting some of the boundary and fringe conditions that need considerable cognitive skills.

It is worthwhile to investigate some of the key challenges facing development of autonomous vehicles.

Ability to respond to spoken commands and hand signals

Autonomous vehicles are deploying sophisticated machine learning and countless hours of actual road testing and yet faltering when it is about encountering subtle signals and body languages of pedestrians, bicyclists, law enforcement officers and highway safety employees.

Safe driving despite missing Lane marking

Driving in clearly marked city lanes in benign weather may not pose major challenges for Computer-driven vehicles. However, unmarked country roads devoid of white lines, Botts Dots or clear demarcations at the edge of the road or snow covered surface poses significant challenges to autonomous vision system.

Reliably recognizing non-working traffic lights

Autonomous car's vision system identifies traffic lights quite reliably. Making correct decisions in the event of a power failure is more challenging.

Making turns into fast-moving traffic

Merging into rapidly flowing lanes of traffic is a delicate task that often requires eye contact with oncoming drivers. Researchers are considering solutions like electronic signs and car-to-car communications systems.

Ability to operate in all-weather condition

Heavy rain or snow can confuse current car radar and LIDAR systems, making it necessary for humans to intervene.

Cybersecurity of autonomouscars

A self-driving car is a collection of networked computers and sensors wirelessly connected to the outside world. Like any other system, it is a target for intrusion and hacking. Intruders may wish to control, crash cars, or turn them into weapons, which is the most daunting challenge facing autonomous driving.

Cost-efficient Technology for Mass Manufacturing

Self-driving cars need at least three kind of environmental awareness functions—LIDAR, which can see clearly in 3-D; cameras, for color and detail; and Radar, with can detect objects and their velocities at long distances. Lidar setup for one car can cost USD 75,000 as a standalone system. Although widespread adoption will rapidly drive down the technology cost in the long term, currently it is a serious roadblock for private adoption.

Ability of Passenger to Interact with Vehicle

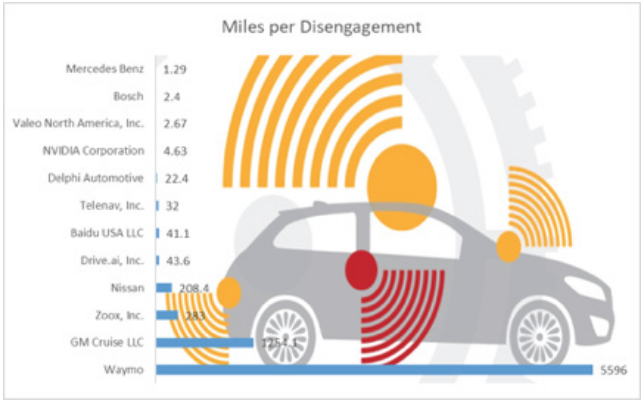
Autonomous cars are being designed to be introduced through a ride-hailing service first. The tech is too expensive, and too dependent on weather conditions, topography, and high-quality mapping, to sell straight to consumers. There is lack of clarity on myriad use cases of riders interacting with the vehicle, and how those would be addressed to make the journey pleasant, safe and convenient.

Camera vs Lidar

TESLA and Intel Mobileye are proponents of Camera-based autonomous system, whereas most others use LIDARs for added accuracy and safety of the system. However, Tesla Autopilot has some limitations especially in identifying stationary objects at high speed. Incidentally, Tesla and Mobileye worked together initially before withdrawing from partnership.

Alliances and competition in Autonomous Technology

Toyota Motors had steadfastly refused to develop autonomous cars until 2014, as it considered driving as an art best perfected by a human driver. However, the next year, Toyota announced an investment of USD 1 Billion in autonomous technology research. Almost all auto majors have embraced the rapidly realizing threat of massive changes unveiling in Auto industry starting from electrification, car sharing and autonomy. Interestingly, autonomous vehicle development seem to come natural to technology firms specializing in software development as it is with traditional auto manufacturers. In terms of advancement in autonomous technology, the familiar secrecy shrouds most of the automakers. However, an oblique reference to technology maturity may be obtained from the Disengagement report published by California Dept. of Motor Vehicle. Based on the data, it seems Waymo (Alphabet Inc) and Cruise (General Motors) are clearly ahead of competitors, and are competing to capture the top slots as the entrants to Autonomous vehicle service.



Autonomous technology development has not been limited to a select club of automakers and permeated across a broad spectrum of technology firms and startups. Since technology development is capital-intensive, traditional auto manufacturers have entered into partnerships with the technology developers in order to bring the offerings to market earlier than originally would have been possible. In the other spectrum are the tie-ups between customers of autonomous technology, majorly ride-hailing service providers and auto manufacturers to define a smooth path of commercialization of the technology.

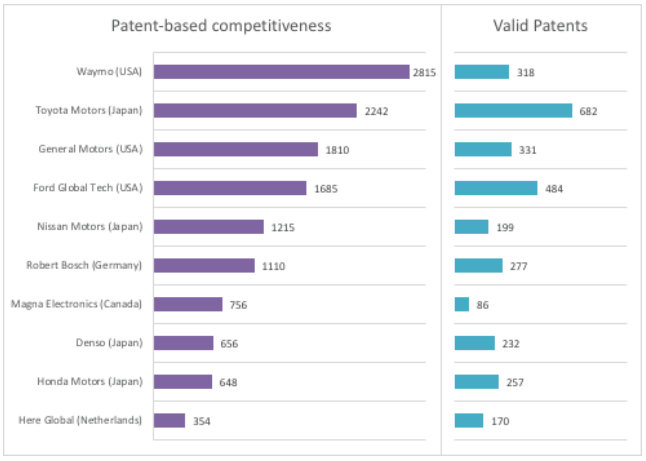
Following are some of the significant recent collaborations across The Automotive and Technology Industry that will probably be redefining the Autonomous offerings in future.

Technology Developers	Auto OEMs/Fleet Operator	Development
amazon	TOYOTA	e-Palette –planning to launch multi-function autonomous minivan at 2020 Summer Olympics/Tokyo; announced partnership with Toyota in CES 2018
Apple		Project Titan to develop autonomous system; Registered with California DMV to conduct road test for its fleet of 66 vehicles in 2018
(Aptiv Delphi) APTIV	lyft	Delphi Acquired nuTonomy in 2017; Completed 5,000+ self-driving rides in collaboration with Lyft
Baidu 百度	CHERY	Built Autonomous system using open-source Apollo Software. Opened an AI lab in Silicon Valley. In 2018, received approval from China to test Apollo in collaboration with Chery Automobile. Plans to test fully autonomous cars by 2020.
Audi		Audi launched flagship A8 with Level 3 Autonomy in Europe in July 2017. Part of German consortium to acquire Nokia's precision mapping asset HERE for USD 3.1 Billion
Autoliv	VOLVO	Volvo entered into an autonomous Joint Venture with Swedish supplier Autoliv in 2017; To commercialize Driver-Assist system Zenuity by 2019; in 2018 Volvo entered into partnership with Lidar startup Luminar to work on physical sensors and data processing; Plans to offer autonomous XC90 by 2021 in Sweden.
intel MOBILEYE	BMW	BMW is collaborating with Intel Mobileye to create an open standard-based platform for Autonomous cars. Plans to launch first autonomous vehicle BMW iNEXT in 2021. Intel acquired Israeli Mobileye in 2017 to boost its offering in autonomous technology
BOSCH	Mercedes-Benz	BOSCH is partnering with GPS-maker TomTom to develop self-driving technology projected to be rolled out by 2020. Mercedes & BOSCH is partnering with GPS-maker TomTom to develop self-driving technology projected to be rolled out by 2020. Mercedes & BOSCH collaborating on developing Level 4 and Level 5 automation with exclusive right to Mercedes for two years.
ARGO AI	Ford	Formed new subsidiary, Ford Smart Mobility LLC in 2016. Plans to rollout advanced autonomous vehicle with Geofenced areas by 2021. Most notable acquisition has been majority stake in AI startup Argo in 2017 for USD1Billion. Tied up with Domino's and Postmates for autonomous delivery.

Technology Developers	Auto OEMs/Fleet Operator	Development
lyft	GM	GM acquired autonomous start up Cruise Automation and invested USD 500Million in Lyft in 2016. Launched Cadillac CT6 in 2018 with Super Cruise. In the process of getting approval for running commercial ride sharing business with autonomous cars (Chevrolet Bolt) in 2019.
GM	HONDA	Introduced semi-autonomous ADAS in Luxury as well as Mass market models. In 2017, launched R&D center X. In talks with Waymo since 2016 to use Self-driving system in its vehicles. In 2018, announced investing USD2 Billion in GM Cruise.
	HYUNDAI	Hyundai collaborated with Autonomous technology startup Aurora. It announced to test an autonomous SUV by 2021 and Go to Market by 2025.
WAYMO	LAND ROVER | JAGUAR	In 2018, Jaguar Land Rover announced a new partnership with Waymo to build a fleet of electric, self-driving cars. Up to 20,000 new Jaguar I-Pace models will be built to serve in Waymo's fleet for its ride-hailing transportation service, with production on the vehicles beginning in 2020.
	NISSAN RENAULT	In 2016, Nissan/Renault announced launching 10 models by 2020 with significant autonomous functionality. In 2017, Nissan started testing autonomous models in Tokyo. In 2017, Nissan joined Crowdsourced vehicle mapping effort by Mobileye. In 2018, Nissan announced collaboration with Japanese Gaming and e-Comm company DeNA on an autonomous taxi service, Easy Ride.
TOYOTA		In 2015, announced $ 1Billion budget for autonomous driving research. It is collaborating with University of Michigan, Stanford University and MIT on autonomous car and Machine learning.
WAYMO	FCA FIAT CHRYSLER AUTOMOBILES	Google started on Autonomous Technology in 2009 on board Toyota vehicles. In 2016, it spun off Waymo to focus on developing Self-driving technology. In 2017, Waymo partnered with FCA and began adding Chrysler Pacifica in the fleet. By 2018, Waymo has clocked 4 Million miles of road driving experience and far ahead of competitors in terms of technological maturity. Waymo ordered 62,000 Pacificas to its fleet and launched commercial ride hailing service in Arizona.
	UBER	Uber collaborated with University of Arizona in mapping and optical safety technology. In 2016, Uber revealed in-house developed Prototype and acquired self-driving truck startup Otto. Soon it was embroiled in legal controversy with Waymo and settled with USD 245 Million equity. After often-turbulent road tests, it was finally involved in a fatal crash in 2018, which forced Uber to stop testing and pullout vehicles. It ended self-driving truck program Otto. Late 2018, Uber announced attracting USD 500 Million from Toyota to work jointly on autonomous vehicle.

Intellectual Property race in Self-driving technology

As advanced Artificial Technology and data defines the future Automotive Sector, Nikkei (Stock index in Tokyo Stock Exchange) has begun assigning ranks to Automakers based on Intellectual Property or Patents filed and patent-based competitiveness. Although Waymo has almost half the patent filed compared to Toyota, it ranks higher in patent-based competitiveness, as its patents are widely known to international examiners as cutting edge and cited extensively.



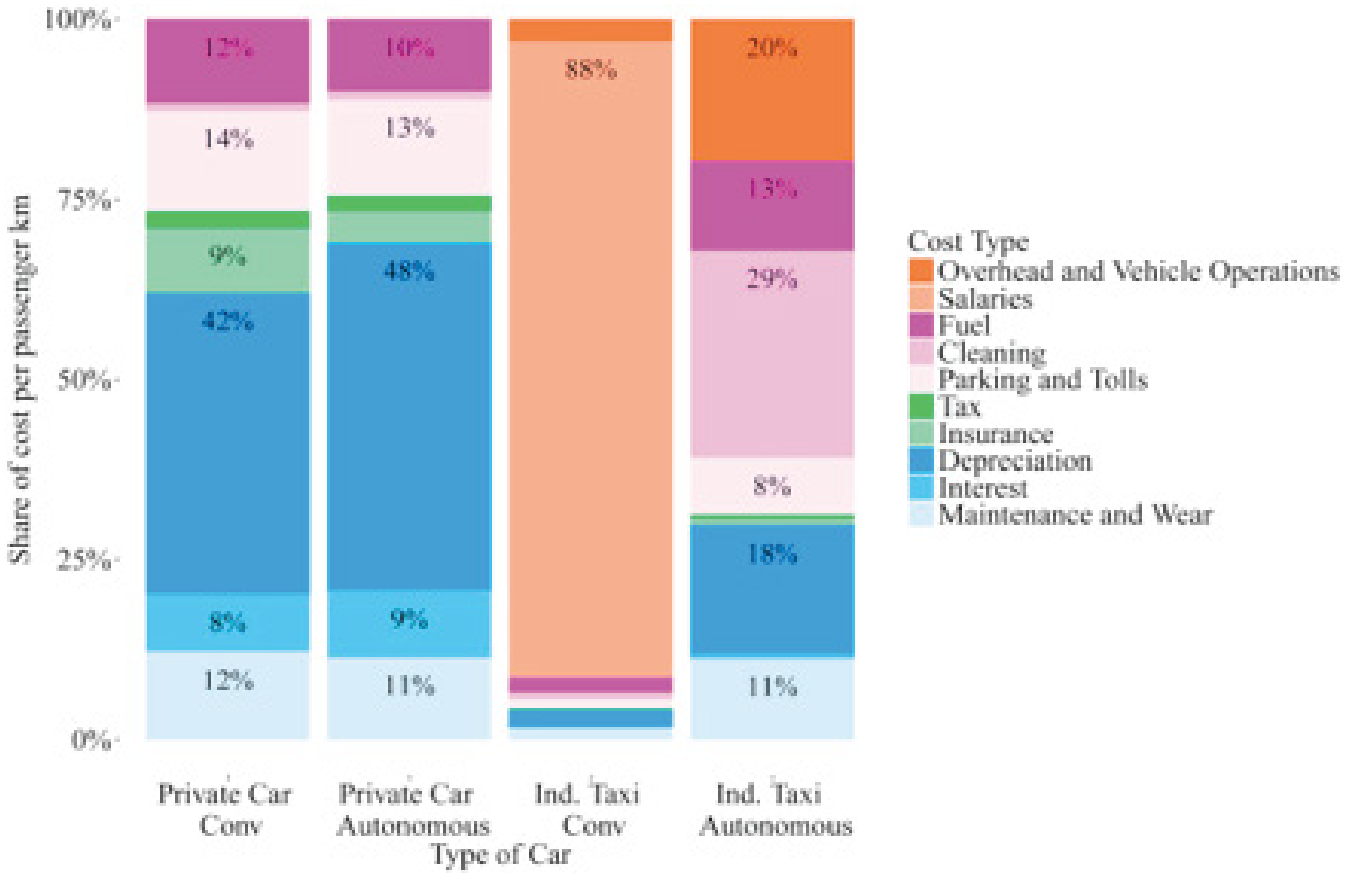
Evolving competition and Leadership in a potential future market

Advanced autonomous vehicles with sensors, advanced safety and convenience are expected to throng the streets as either Ride-hailing or Delivery services. Except for a limited launch of Waymo's app-based autonomous shuttle service in suburbs of Phoenix (AZ) in 2018, none of the competitors has officially launched autonomous services or products in the market so far. However, GM is probably the nearest competitor to Waymo and is expected to launch autonomous ride hailing services through GM Cruise in 2019. It has built a scalable platform to track the self-driving cars in the real-time and direct them to customers, who would be using App based ride booking facility. Close on the heels would be Ford Motors, which is scheduled to launch autonomous shuttle and delivery services in 2021 in a grand scale. FCA the third in the line of Detroit's Big Three, has invested USD30 Billion in development and testing of autonomous vehicle and advanced safety technologies. Meanwhile, FCA has also entered into an alliance with BMW and Intel Mobileye to jointly develop and mature the autonomous technology. Interestingly, FCA also provides vehicles for Waymo's Autonomous fleet besides alliance with BMW. Another behemoth Volkswagen AG has pledged pumping in USD 50.2 Billion in Autonomous research up to 2023. Among Japanese car makers, Renault Nisaan is entering into partnership with Waymo to fast track its autonomous taxi and other service development on autonomous platform.

Auto OEM	Strategic Measures	Corporate Action	Target to Launch
GM	• $581 Million Cruise Automation 2016 • $500 Million 9% stake in Lyft	Acquisition / Partnership	2019
Ford	$1 BnBillion Argo AI		2021
HONDA	Waymo GM	Partnership / Investment	2020
TOYOTA	$1 Billion	Investment	2020
NISSAN RENAULT	Microsoft	Partnership	2020
VOLVO	$300 Million JV with Uber	Partnership	2021
HYUNDAI	$1.7 Billion in R&D	Investment	2020
DAIMLER	Uber	Partnership	2020-2025
FCA	Waymo	Partnership	NA
BMW	Intel Mobileye	Partnership	2021
TESLA		Investment	2019

Cost Impact of Self-driving cars

A detailed analysis on Cost of Autonomous Mobility services by Patrick M.Bösch, Felix Becker, Henrik Becker, Kay W. Axhausen clearly indicates the financial viability of autonomous fleet of vehicles over privately-owned autonomous vehicle . A comparison of two different operating models – Privately-owned Vehicle vs Commercial fleet taxi, shows that while operating cost of a private vehicle is determined by Depreciation, Insurance, interest cost, etc that depend on the fixed purchase cost, operating cost of a fleet vehicle is decided by the driver's salary and to far lesser extent by administrative costs. While self-driving vehicles are most likely to command a higher price point, their significant high utilization would result in substantial reduction in variable cost including labor cost, which will outweigh the acquisition cost hike for ride-hailing services. The study indicates that more than 50% of fleet operating cost would result from Management and service costs. As a result, if all other cost components remain unchanged, operational efficiency will determine the market share. However, over a period, operating cost of fleet will be lower than private vehicles. This will cause a new paradigm shift in vehicle ownership and vehicle utilization, which may observe substantial reduction in retail vehicle demand for Auto manufacturers.



Conclusion

Automotive industry has witnessed major consolidation over the years, driven by technology and market leadership. However, at a core product level, the key differentiators have been fuel economy, reliability and cost competitiveness. The advent of autonomous vehicle completely shifts the focus to technology, driven by connectivity, data and computational power. As we observe a confluence of innovative Power Train (Electric, Fuel cell and Plug-in), connectedness and self-driving vehicles, the core foundation of auto manufacturing is observing a tectonic shift. As collision becomes rare and vehicle ownership less attractive, complete business model and value chain of Auto industry will undergo rapid shift. This upheaval will get initiated at a basic supplier level right up to the service and parts business.

The initial focus of autonomy will be commercial fleet and mass transit, which will help market leaders to rapidly break-even with scale. As regulations and legal responsibilities for future use cases of self-driving eco-system attain greater clarity, first movers would be at an advantage.

Within the next decade, there is a high likelihood that the next taxi service we avail out of an airport would probably be an autonomous one.

About the Author

Manabendra Mukherjee
Project Manager, Digital Consulting & Advisory, LTI

Manabendra has over 14 years of experience across Manufacturing and Information Technology, and has been assisting clients in various transformation programs embrace Next-gen Digital Technologies including IIoT, Robotic Automation, Cognitive Computing to drive productivity and business growth.