

The Impact of Autopilot on Tesla

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Abstract. As Tesla advances in technology, Tesla is expeditiously embarking on exploring an emerging field, driverless technology. Due to the current instability of driverless technology, driverless systems are not commonly used at the moment. Nevertheless, its impact on Tesla can not be neglected. Therefore, this study focuses on the impact of the emergence of autonomous driving on Tesla. Specifically, this paper explores the impact brought about by autonomous driving by collecting statistical data, gathering real-life cases, and analyzing the information. However, the research illustrates that Tesla's Autopilot is a double-edged sword. It damages the reputation of Tesla while offering the huge potential for gaining tremendous revenue in the present and future. In the long run, the scales are tipped in favor of autonomous driving technology. Thus, persisting in exploring the field of driverless technology will speed up the promotion of Tesla.

Keywords: *Driverless technology, Autopilot, Statistical data, Real-life cases.*

1. Background

With its headquarters in Austin, Texas, Tesla is a transnational American automotive and clean energy corporation. Hastening the world's transition to sustainable energy is Tesla's overarching objective. Tesla creates solar roof tiles, electric vehicles, grid-scale battery energy storage, residential batteries, and other associated commodities and services [1]. Martin Eberhard and Marc Tarpenning form Tesla, Inc., formerly Tesla Motors, on July 1, 2003. Later on, Elon Musk joins Tesla and makes use of the \$6.5 million capital injection as the chairman of the board of directors and the company's largest shareholder.

Initially, Tesla's strategy is to launch a high-end sports car targeted at early adopters before transitioning to more popular models, including sedans and inexpensive compacts. In 2006, Tesla officially reveals the prototype of its first car, the Roadster, and Tesla commences producing the Roadster in large quantities in 2008. After two years, Tesla goes public in 2010 with an initial public offering on NASDAQ, an electronic exchange where investors can purchase and trade securities on an automatic computer network. In 2012, Tesla switches their original plan, producing Roadsters, to selling the Model S luxury sedan, which becomes the top of the new car sales list in 2013. After that, Tesla makes a breakthrough in the self-driving industry. They invent the Tesla Autopilot in 2014, which is a Level 2 system that allows vehicles to control steering, accelerating, and decelerating. In 2015, Tesla enters the energy storage industry, manufacturing two neoteric battery packs, one for home and another one for business. Simultaneously, Tesla begins shipping the sumptuous SUV in September 2015, which is the Tesla Model X. Then, Tesla acquires SolarCity and marches the photovoltaics market in 2016. Tesla combines its current battery energy storage products and the solar installation business forming the Tesla Energy subsidiary.

Furthermore, Tesla starts shipping the Model 3 sedan in 2017, which offers an affordable price for the mass market. After two years, Tesla establishes its first Gigafactory in Shanghai, China. Subsequently, Tesla opens a new Gigafactory near Berlin, Germany, and another in the Texas, USA, in 2020. Instead of focusing on expansion, Tesla turns its focus to selling the Model Y when they finished the construction of three Gigafactory. Meanwhile, Tesla reaches four huge milestones in its valuation from 2020 to 2021. First of all, Tesla achieves an \$86 billion market value, turning Tesla's

valuation into the greatest one among all American automakers on January 10, 2020. In the following month, Tesla attains a market capitalization of \$206 billion, becoming the most valuable automaker all over the world. What's more, the growth of Tesla is inexorable. The market capitalization of Tesla comes to \$848 billion on January 26, 2021. Last, Tesla's valuation reaches \$1 trillion in October 2021, being the sixth company that has over \$1 trillion market capitalization in U.S. history. However, Tesla's success is crucially linked to the innovative devices it has invented, such as Powerwall and Megapack. Tesla creates the Powerwall, an integrated battery system that saves solar energy for backup conservation and lessens dependency on the grid. The gadget spontaneously detects power interruptions and recharges utilizing sunshine. And, Tesla Megapack is revolutionizing how the grid is powered, enabling the world's largest energy projects. Take the 1 Gigawatt hour project as an example, it can provide record energy capacity since the energy supply is ample to power every residence in San Francisco for six hours [2].

Additionally, Tesla Autopilot becomes one of the most potential technologies, being the beacon of the future's development. Tesla Autopilot is a suite of the advanced driver-assistance system (ADAS) features manufactured by Tesla, which is equivalent to Level 2 vehicle automation [3]. In May 2013, Elon Musk raises the idea of autonomous vehicles in a public forum. Citing the safety and efficiency of using autopilot in airliners, Musk states that installing autopilot on the car will be a good idea. Therefore, he starts working in this field.

In the early stages of planning for the Tesla Autopilot project, Musk and Google explore the possibility of jointly developing a highway autonomous driving system. Meanwhile, Google launches a semi-autonomous driving system, AutoPilot, in 2013, but Google's technology does not end up in mass production on Tesla, mainly because Google stops testing AutoPilot. At the time, Google invites a group of employees who have to commute long distances via highways every day to participate in testing the system. A few weeks later, one employee falls asleep during the testing. John Krafcik, the current CEO of Google Waymo, explains the reasons for stopping the development of Autopilot. The team believes that semi-autonomous driving systems are unreliable since the better the system the company builds, the more likely people are to over-trust it. And, accidents are more likely to happen. After calling off the semi-autonomous driving project, Google and Tesla take two completely different paths, with Google moving into full development of L4-L5 fully autonomous vehicles that do not require human involvement, while Tesla continues to develop the first generation of Autopilot.

Soon, Tesla creates HW 1.0, Autopilot Hardware 1.0, designed by the Israeli engineering firm MobilEye, but they break ties with Tesla because of safety concerns, styles, and data attribution. The HW 1.0 contains 12 ultrasonic sensors, a forward-looking camera, a radar, and a digital operating platform. From Tesla's perspective, accelerating the development of driverless technology is paramount, resulting in Tesla's decision to use an incremental strategy of rapid error correction and fast iteration, which is installing the hardware first and updating the software continuously via OTA. OTA, over-the-air, allows users to persistently update and improve the car's performance and user interface features. Eventually, complete systems are received by users in October 2015. Before receiving the complete systems, users are using the software version 6.0, which introduces traffic-based navigation and commute advice, displays an in-car view of daily schedules, and enables location-based air suspension settings. Further, with version 7.0, the Tesla Model S is able to use a combination of radar, cameras, data, and ultrasonic sensors to autonomously navigate along the highway, change lanes, and adjust the speed in response to traffic. As you arrive at the destination, the vehicle will search for a parking spot on your command and display it on the screen. In next version, version 7.1, Tesla makes improvements including Autosteer, Summon(Beta), Perpendicular Autopark, Enhanced Autopilot Visualizations, Traffic-Aware Cruise Control Improvements, Additional Autopilot Improvements, HomeLink: Auto-Open/Close, Vehicle Lock Improvements, Display Auto-Brightness, Supercharger Site Availability, Trip Planner Improvement, and Additional Improvements. At the end of 2016, Tesla offers the last version of Autopilot HW1, version 8.0. In version 8.0, it improves the Intuitive Media Players, Voice Commands, Maps, Navigations, Cabin Overheat Protections, Trip Planners, and Autopilot Enhancements.

In comparison to the previous version, the Autopilot HW 2 has a rear camera, 3 front cameras, 4 side cameras, a front radar that enables to range 160 meters, and 12 ultrasonic sensors with the range of 8 meters. Also, Tesla utilizes the NVIDIA DRIVE PX 2 AI computing platform rather than the Mobileye EyeQ3 computing platform. Changing the computing platform highly increases the hash rate and efficiency. Meanwhile, adding more facilities allows it to be able to detect a wider range. However, Musk claims they still have to make huge progress in the visual aspect within two months. To fulfill this objective, Musk and his team get support from several crucial people, such as Jinnah Hosein who is from SpaceX, and Chris Lattner. Those people lead Autopilot to a higher level. Consequently, the Autopilot HW2 version 8.1 is published in May 2017, which contains the following adjustments. First, the steering wheel automatic steering speed limit increased from 55mph to 80mph. Second, users can park and retrieve the car from outside the vehicle. Third, the update will also add enhanced lane departure alerts for drivers as well as the new Auto Lane Change feature, which enables the car to change lanes on its own when the user flicks the turn signal while Autosteer is running. Fourth, a new Headrests Adjustments function enables lumbar and headrest seat adjustments to be made via the touchscreen by the driver. Last, Tesla also makes it possible to use voice commands to launch a map search for a certain location. When you request "Take me to the nearest Mcdonald's," the map will display a list of nearby establishments with that name.

In July 2017, Tesla makes a slight update on HW 2.0, forming HW 2.5. Firstly, the front/side cameras are replaced from the RCCC filter to the RCCB filter. Secondly, the millimeter wave radar is replaced by Bosch 77GHz medium range radar MRR to Conti long-range radar ARS410. ARS410 can obtain a wide field of view through two independent scans. Thirdly, a Parker processing chip is added to the computing platform to provide more strong computing performance. Also, the PCB board is optimized. Finally, the wire control system is optimized with dual cable communication on various important components such as steering and brakes, in case one cable fails, the backup cable can be enabled to continue driving. In April 2019, Tesla starts using the Full self-driving computer hardware 3, FSD HW 3. It contains two identical processors designed by Tesla, and the forward radar is removed. According to Tesla's report, Tesla asserts that HW3 has 2.5 times the upgraded performance of HW 2.5 with 1.25 times superior power and 0.2 times lower expense. HW3 consists of twelve ARM Cortex-A72 CPUs operating at 2.6 GHz, two Neural Network Accelerators operating at 2 GHz, and a Mali GPU operating at 1 GHz [4].

2. Technical uniqueness

Compared with the technologies that other companies used, Tesla has the following unique technologies. Firstly, Tesla's latest perception solution uses a purely visual perception solution. Tesla no longer uses non-camera sensors such as LIDAR and millimeter wave radar and uses cameras as the eyes of the car for perception, which is extraordinarily distinctive in the whole industry of the autonomous vehicles. The combination of eight cameras and powerful vision processing offers 360 degrees of visibility, covering the maximum distance of 50 meters surrounding the whole vehicle with a unidirectional maximum distance of 250 meters. Secondly, the "HydraNet", the visual perception network of Tesla, is composed of a Backbone, a Neck, and several branching Heads. The core feature of HydraNet is that multiple subtask branches share the same feature space. Compared with using separate neural networks for a single task, HydraNet avoids the phenomenon of repeated computations between different tasks and effectively improves the overall operational efficiency of the network. At the same time, each task runs independently without affecting the other tasks, thus upgrading a single task can be done without having to verify that the other tasks are working properly at the same time, making it less expensive to upgrade. In addition, the generated feature space can be cached, making the tasks more flexible, which is highly scalable.

What's more, three virtual layers promote the precision of Tesla Autopilot. First, the data calibration layer will add a layer of "virtual standard camera" to the original perception framework. By distorting and rotating the initial data using image data captured by other vehicles and adding the

edited data to a larger system, the original data from each camera is calibrated to eliminate extraneous errors and ensure data consistency. Second, the spatial understanding layer refers to the uniqueness of Tesla's ability to transform dimensions. Because the data collected by Tesla's cameras are 2D images, the images do not correspond to the real-world 3D space. Therefore, Tesla introduces a BEV spatial transformation layer into the network structure. The BEV coordinate system, which is an aerial view coordinate system, is used by Tesla to build the spatial understanding capability of the network. The core module of Tesla's 3D transformation is Transformer neural network, which is an attention mechanism-based deep learning system. The transformer neural network will filter the unimportant information and focus on the key messages, leading Tesla to be able to achieve accurate perception and prediction of object depth information by this method. Third, the short-term memory layer makes it possible for the system to possess similar memory ability to remember data features from a certain time, making Tesla's functionality more agile, as Tesla's system can provide an estimated process mode through scenarios experienced in the past. Additionally, Tesla's systems have powerful Computing power that is brought by Dojo, a supercomputer constructed by Tesla. On Tesla's Open AI day, a model of its d1 chip tile is unveiled [5]. All of these will accelerate the accomplishment of self-driving systems.

3. Merits and demerits

However, as one of Tesla's major R&D projects, Autopilot is not only profitable but also has great potential. The standard autopilot is an accessory of the vehicle, but the EAP, Enhanced Autopilot, and FSD, Full Self-Driving, are valuable and their prices have been increasing since they were published. EAP charges 6 thousand dollars in 2018, and FSD charges either twelve thousand dollars at once or 199 dollars per month for the subscription in 2022. According to Western Securities analyst Dale Yame in a research report, with the rise of Tesla's sales, the business model of "hardware pre-built and software fees" will become a giant contribution to Tesla's revenue. According to the financial report published by Tesla, it shows that Tesla's service revenue for the third quarter of 2021, including FSD, is 894 million dollars. Specifically, 894 million dollars means around 6.5 percent of the company's total revenue, 13,757 billion dollars, is brought by the discovery of the field of autonomous vehicles. Unlike other self-driving companies, because Tesla's FSD is fully self-developed, the company gets 100 percent of the revenue, which will bring Tesla huge profits. The financial literature on INSIDE EYES has revealed the estimation of the future profit brought by FSD, which is made by Loup Ventures. Full self-driving (FSD) purchases and subscriptions are anticipated to generate USD 102 billion in profits for electric vehicle company Tesla by 2032. Loup Ventures believes that the operating profit margin for FSD will rise from 42 percent in 2021 to 64 percent ten years later [6].

Moreover, the FSD take rate is one of the main factors that determine the FSD revenue. Based on the worldwide survey, concluded by Troy Teslike, which is covered on over 17,000 Tesla car owners, Troy Teslike uses a line graph showing that the FSD take rate is relatively stable since the rate is approximately 13 percent except for the take rate in 2019. In 2019, Tesla removes the EAP, Enhanced Autopilot, so that the FSD take rate is highly increased to 46 percent in the second quarter of 2019, and it decreases to 11 percent in the second quarter of 2021. Another survey on the FSD take rate by different models in North America also proves the previous perspective. The FSD take rate is steady. The FSD take rates of Model S/X maintains at around 63 percent from 2020 to 2021.

In contrast, Tesla's reputation is being influenced while Tesla is experiencing the growth of the company. Autopilot is also a double-edged sword, bringing many concerns and criticisms to Tesla. Since 2018, the safety of autopilot has continued to be a hot topic for Tesla which causes a customer belief crisis to some extent.

In the United States, Car incident data is first collected in 2022 since the NHTSA (The National Highway Traffic Safety Administration) started compulsory execution in June 2021 that all automakers must report car accidents that involve "Level-2" ADAS (advanced driver-assist system)

[7]. After the data is first released a year later, Tesla is once again pushed to the cusp of public opinion. On June 15th, 2022, the United States safety agency indicates that Tesla accounts for most driver-assist crashes. Throughout the year, nearly 70% (273) of 392 recorded car crashes involving ADAS come from Tesla. The following car companies will be Honda (90 reported accidents), Subaru (10), and Ford Motor (5), and the rest companies including Toyota, BMW, and General Motors will be less than 4 accidents in the past year [8].

In terms of the severity of those Tesla car crashes, it will be exemplified by three car accidents recorded from the earliest to the recent ones.

In 2019, reported by The New York Times that two men aged 59 and 69 were taking the autonomous driving system and get crashed in Texas, US. Under the autonomous control, the 2019 Model S kept its high speed in a curve. It then went off the road for approximate 100 feet and hit a tree and burst into flames. [9]

On May 12, 2022, on the Pacific Coast Highway in California, three people were killed in a Tesla when it hit a curb and crashed into construction equipment [10].

1. On July 27th, 2022, in Draper, a Tesla driver using Autopilot careened into the rear of a bike and made that motorcyclist killed. [11].

What is worth noticing is that NHTSA has been investigating Tesla since 2016 and listed out that Tesla Autopilot took place in 32 out of 35 special crashes, which leads to some customer belief crises. Although Tesla's official website announces that the Current Autopilot is not yet for fully autonomous driving which still needs active driver supervision, Tesla has been charged for misleading drivers about their cars' actual capability [12]. With the high rate of fatality in the incidents of Tesla, the actual capability of Autopilot was put into question. Surprisingly, Tesla does not interest in dealing with these public anxieties, since Elon Musk dismissed Tesla's whole press department in 2020 [13]. Instead, even though the crashes seem more and more common, especially for the fatal crashes involving Autopilot, Tesla has continued to argue that its cars are safer than average vehicles. This action enlarges customers' cognitive bias toward the actual and true capability of Tesla Autopilot, leaving a further impact on Tesla customer loyalty [14]. This is best exemplified by the unprecedented drop in Tesla share prices. As recorded, on May 17th, 2019, with the report of fatal crashes involving the Tesla Autopilot system, Tesla shares dropped almost 8% on that day which hit their lowest price since 2016 [15].

Besides, recalls for the Autopilot software issue can also be a headache for Tesla. Based on the detecting flaws of Tesla from NHTSA, Tesla was announced to recall for the software issue covering some 2016-2022 Model X and Model S, 2017-2022 Model 3, and 2020-2022 Model Y vehicles. It happens more frequently for the software issues in Tesla when it augments its production to a global scale. In November, approximately 12,000 U.S. Tesla vehicles sold after 2017 were recalled for another software update. It is driven by the communication error that would cause a false forward-collision warning or unexpected activation of the emergency brakes. Lately, in January 2022, for the new rear camera problem, Tesla recalled 675,000 Model 3 and Model S in both the USA and China [16].

4. Conclusion

The purpose of this research is to identify the impacts of Tesla's new project Autopilot on the development of Tesla from both positive and negative aspects. Based on the analysis conveyed, it can be concluded that the launch of Autopilot does bolster the development of Tesla, making it a leading company in both ADAS and the driverless car industry. As for pros, Autopilot makes Tesla stand out as a unique company among all the automakers with its innovative technological advancement: replacing the conventional LiDAR system with the combination of eight cameras around the car; applying the high working efficiency system "HydraNet" which avoids the repeated computations between different tasks; upgrading with BEV spatial transformation layer to assist transforming 2D images captured to real-world 3D space, thus for detecting the real world situations.

Moreover, according to the data collected, Autopilot is of great significance in Tesla's profit sector and prospects. The increasing price of EAP and FSD as the advanced part of Autopilot renders a giant contribution to Tesla's revenue since all the Autopilot systems are self-developed with a hundred percent of profit. As expected, they will continue being a bulk of Tesla's future gains.

However, in the light of increasing incidents of car crashes since 2016, Tesla has been titled a "cheater" for misleading the customer's understanding of the actual capability of Autopilot and constantly no feedback pushed Tesla to the cusp of public opinion. More and more people started to doubt the true capability of Autopilot, and as a result, lost its branding as the "safest vehicle" to some extent. Over 10,000 recalled cars in terms of flaw fixing every year on average is also a big problem for Tesla.

Thus, based on all the information mentioned above, demonstrates that the innovative Autopilot system brings Tesla great fortune and renders it a leading company in the autonomous vehicle industry. Whereas the increasing car crashes involving Autopilot indicate that it is technologically immature, which is understandable, Tesla should start to take steps to forestall those problems rather than wait for the problems to come out. By weighing the pros and cons of Autopilot, it is considered to be a successful innovation of Tesla and it will be one of the big contributors to Tesla's future success.

In a nutshell, this research generally provides a bigger picture of Autopilot in Tesla, including its years' development from the standard Autopilot which is an accessory for automobiles to advanced ones including EAP and FSD. It collects various detailed information about Autopilot such as the initial start-ups, later innovations, and its indispensable contribution to Tesla's current success. Thus, this report will offer great help to some researchers or investors to create a general framework for the Autopilot of Tesla. However, due to the insufficient data posted by Tesla, research analysis of Autopilot cannot go into the more detailed region, for example, there needs to have more data to predict the relatively more precise future performance of Autopilot as well as its future coverage to electrical automobiles who aims to provide driverless-system services. In the later days, our research team will keep up with the performance of Autopilot to provide a more comprehensive analysis of Autopilot.

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