Tesla Vehicle Deliveries and Autopilot Mileage Statistics

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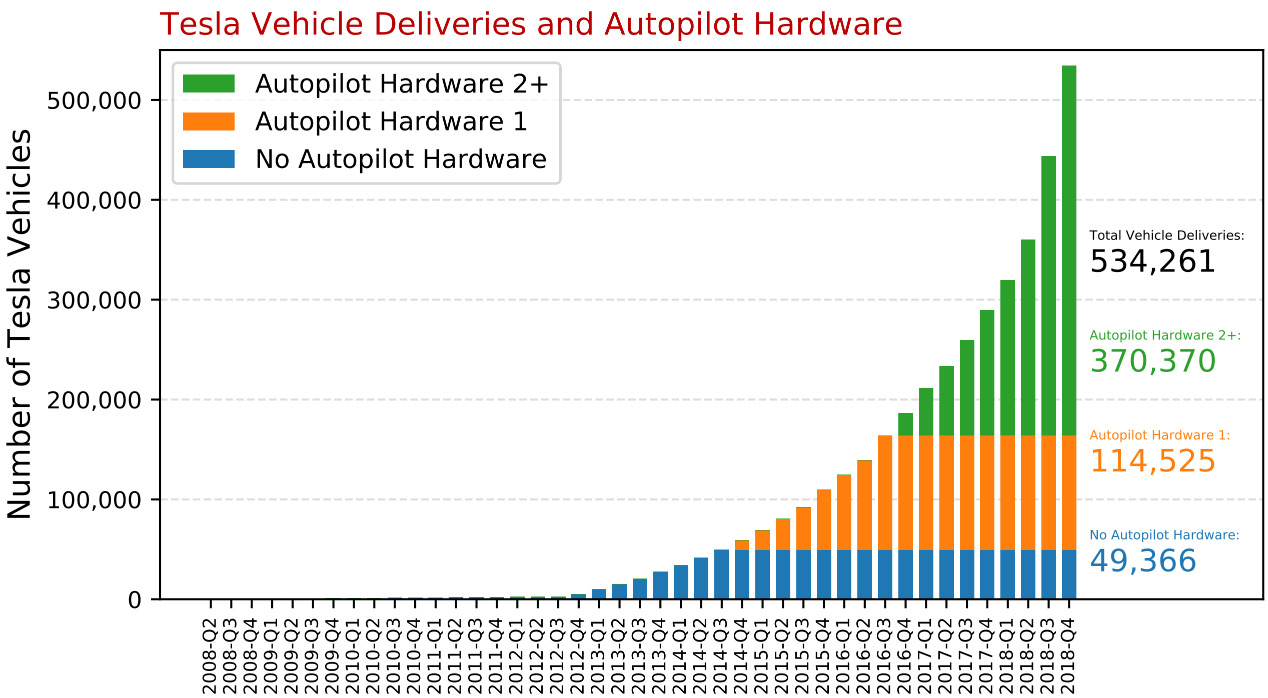

Fig. 1: Tesla vehicle deliveries by Autopilot hardware version.

***Abstract*—There are as many paths to mass adoption of autonomous vehicle systems as there are people, companies, and governments willing to try to engineer and support the development of such systems. Opinions vary vastly. Many researchers, engineers, and policy-makers believe that *semi-autonomous* systems are too difficult to engineer safely and effectively due to the human factor of vigilance degradation in out-of-the-loop supervision of automation. On the other hand, many believe that *fully-autonomous* systems are too difficult to engineer safely and effectively due to the enumerable edge-cases that must be accounted for by perception, control, and planning algorithms including especially cases that involve complex, non-verbal communication with human beings. Like for many problems in machine learning, robotics, and artificial intelligence, the transition from prototype to large-scale real-world deployment can fundamentally change our understanding of the underlying problem and the set of approaches that are effective at solving it. The truth emerges when the rubber hits the road. Motivated by this real-world perspective, this paper details an approach to estimate and project into the future the number of miles driven in Tesla vehicles based on vehicle delivery rates and system utilization. Tesla Autopilot has driven over 1 billion miles to date and is forecasted to reach over 2.3 billion miles by the end of 2019.**

I. Overview

Several semi-autonomous and fully-autonomous vehicle systems have been tested and deployed on public roads over the past decades. They vary in degree and kind of automation, the bounds on intended performance, the limitations of actual performance, and the overall experience considered from the perspective of the humans inside and outside the car that uses the system [1]. Researchers, engineers, and policymakers have proposed and continue to propose many ideas of how to build and deploy effective and safe autonomy systems [2]. Such ideas are not always grounded in real-world data, which is usually true of any new technologies, especially ones that are safety-critical. The goal for this report is to present estimates of real-world usage of Tesla Autopilot and to motivate similar reporting and analysis for other large-scale deployment of semi-autonomous and fully-autonomous systems. Use estimates are especially important for estimating safety characteristics for risk-benefit analysis of specific automated driving and advanced driver assistance systems.

The approach, detailed in the report, provides estimates

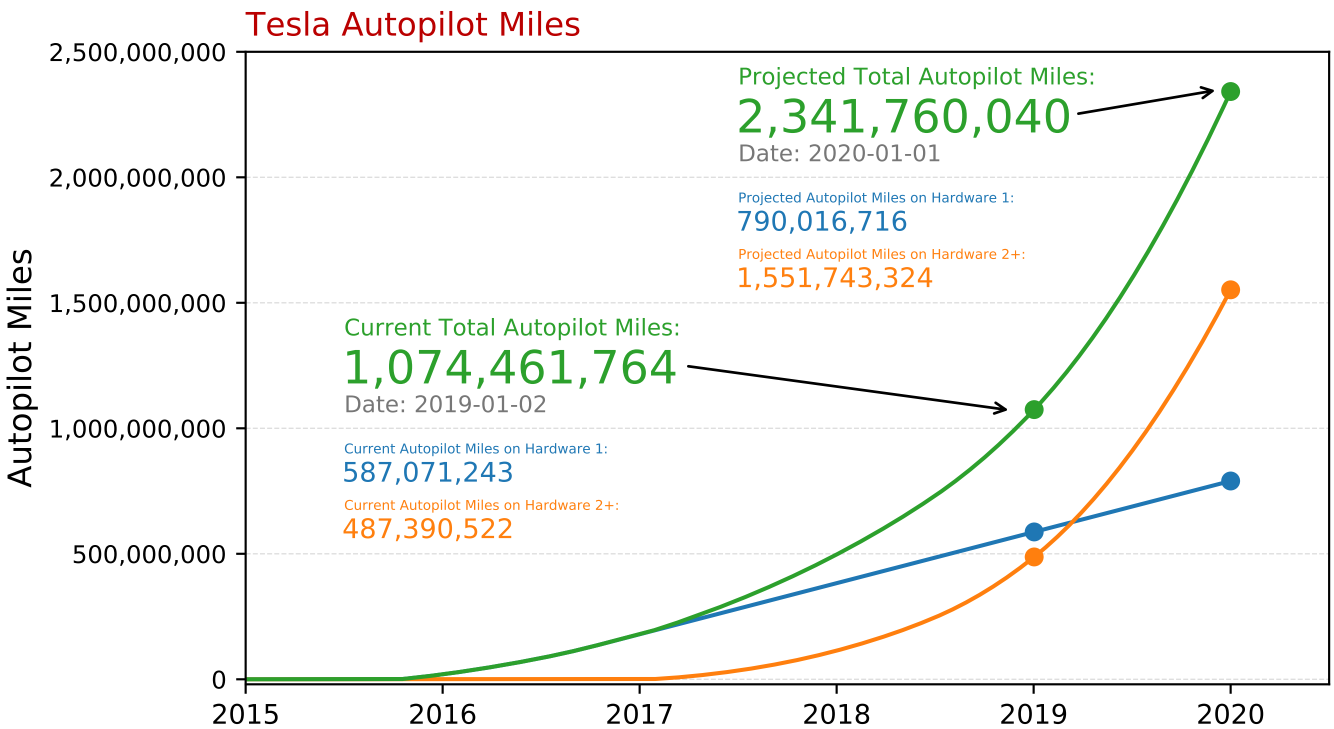

Fig. 2: Autopilot miles traveled: total and separated by generation of Autopilot hardware.

grounded data from various sources including public reports and data collected as part of the MIT Autonomous Vehicle Technology study [3]. The key estimates derived in this report are as follows. As of January 2, 2019:

- **Vehicle Deliveries:** 534,261 Tesla vehicles have been delivered, of which 484,895 are equipped with Autopilot capable hardware.
- **Autopilot Miles:** An estimated 1.1 billion miles have been traveled with Autopilot engaged, and 2.3 billion miles are projected to be traveled by the end of 2019.

Data and statistics supplemental to this report are provided online at https://hcai.mit.edu/tesla-autopilot.

II. Terminology

The terms and abbreviations used in the rest of the report are defined as follows:

- **AP:** Autopilot [4]. General term to describe the system that fuses camera, radar, GPS, and ultrasonic sensors in order to make automated vehicle movement decisions. This includes TACC, Autosteer, Summon, Auto Lane Change, Autopark.
- **AP-HW-2.5:** Autopilot *hardware* version 2.5 (or any other version number).
- **AP-SW-8.1:** Autopilot *software* version 7.0 (or any other version number).

III. Timeline

Tesla, Inc. is a technology company that, among other things, builds electric vehicles and has created one of if not the most frequently used SAE Level 2 automated driving system [2]. Key milestones in the evolution of Tesla's Autopilot feature [5] important for the focus of this document is as follows. Dates are showing when the technology was made available (production and sale).

- **Jul-2003:** Tesla founded.
- **Jun-2012:** Tesla Model S released.
- **Sep-2014:** AP-HW-1.0 installed (AP not enabled).
- **Sep-2015:** Tesla Model X released.
- **Oct-2015:** AP-SW-7.0 released.
- **Jan-2016:** AP-SW-7.1 released.
- **Sep-2016:** AP-SW-8.0 released.
- **Oct-2016:** AP-HW-2.0 released.
- **Mar-2017:** AP-SW-8.1 released.
- **Jul-2017:** Tesla Model 3 released (with AP-HW-2.5).
- **Aug-2017:** AP-HW-2.5 released (to S and X).

IV. Vehicle Deliveries

There are currently three commercially-available Tesla vehicles that have Autopilot: Model S, Model X, and Model 3. The primary source for the data that follows are the quarterly investor letters. These were processed to generate a quarterly estimates of Tesla vehicles delivered (by model) with minimal interpolation except before 2012 when information on Roadster deliveries was sparse. This dataset is available online at: https://hcai.mit.edu/tesla-vehicle-numbers. Fig. 1 shows the total number of delivered vehicles, segmented by Autopilot hardware.

Note that production rate is distinct from delivery rate. Either can be larger than the other depending on various factors. Whenever possible we provide numbers on deliveries and not

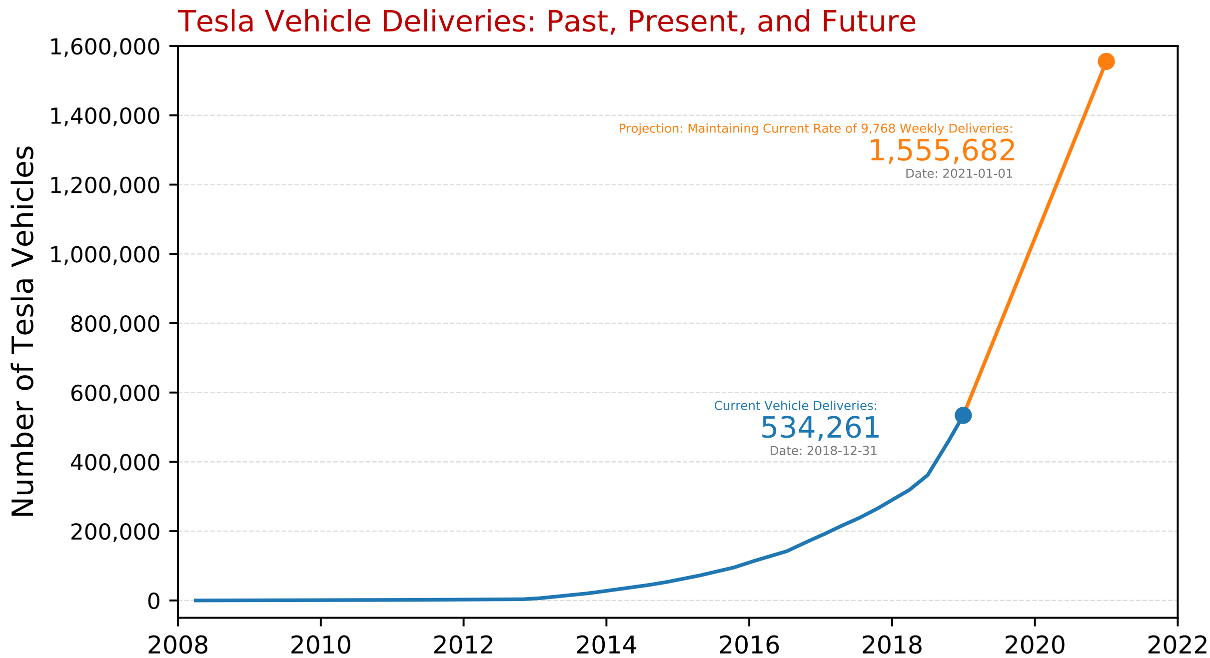

Fig. 3: Daily estimates and projections of past and future Tesla vehicle deliveries. Dataset available online [6].

production. The former is what ultimately defines the point at which we can start counting miles (see §V).

There are two notable observations. First, there are over 484,000 Autopilot-capable Tesla's on public roads. Second, there are now more Autopilot hardware version 2 cars delivered than version 1.

V. Autopilot Mileage Statistics

In order to estimate Autopilot miles traveled, we started from the data aggregated on the number of Tesla vehicles delivered by quarter and organized by Autopilot hardware version in §IV. Next, we did an estimate of per-day deliveries dating back to 2008 in a way that fits the quarterly reported delivery numbers. In the 3 months, between delivery reports, a uniform level of production and deliveries is assumed when computing the interpolation of per-day deliveries. The final result of the interpolation is that for every day since the founding of the company, we have an estimated number of vehicles delivered, broken down by whether they are Autopilot-capable and what hardware version of Autopilot they are installed with as shown in Fig. 1. Additionally, we project vehicle deliveries based on the most recent quarter's delivery rate as shown in Fig. 3. This allows us to estimate, for both past and future, the number of vehicle miles driven under manual and Autopilot control. The resulting daily estimates are available online at: https://hcai.mit.edu/tesla-autopilot-miles.

There are two notable periods that were accounted for:

- Hardware 1 production started (approximately) on 10/1/2014 but Autopilot was not enabled on that hardware until 10/15/2015.
- Hardware 2+ production started (approximately) on 10/19/2016 but Autopilot was not enabled on that hardware until 1/21/2017.

The data points on mileage (overall and in Autopilot) came from various sources online [7], [6]. These samples allow for us to use the above approach to interpolate and project miles traveled per vehicle per day (overall and in Autopilot). The methodology is as follows. First, determine the latest Autopilot mileage reported by Tesla. Next, compute the total number of Autopilot-capable vehicle days from the launch of Autopilot to the date of the latest report. This is based on the interpolated AP1 and AP2 vehicle delivery data behind Fig. 1. Finally, the rate of Autopilot miles per vehicle per day is computed by dividing the latest estimate by the number of Autopilot-capable vehicle days. This rate is used to estimate future mileage based on the projected vehicle deliveries as in Fig. 3.

The number of miles driven per vehicle per day over the past 4 years has remained steady around 32 miles/day (ranging from 31 to 33). The latest estimates are as follows:

- Average Tesla miles driven per vehicle per day: **32.29 miles/day**.
- Average Autopilot miles driven per Autopilot-capable vehicle per day: **4.69 miles/day**.

The Autopilot miles per day in Autopilot-capable vehicles decreased from 7.91 miles/day in November 2016 to 4.69 miles/day in December 2018, while the number of miles driven per day remained steady (31.76 compared to 32.29). The cause of this is likely the distinction between "Autopilot-capable" and "Autopilot-enabled" vehicles. With the release of the Model 3, it is reasonable that a smaller percentage of owners elect to purchase the enhanced Autopilot option, which costs $5,000 at vehicle purchase time or $6,000 at a later date.

VI. Conclusion

Tesla has put over 484,000 Autopilot-capable Tesla vehicles in the hands of consumers and has driven an estimated 1.1

billion miles under Autopilot control. This scale of human-machine interaction in the real world provides an opportunity to study and understand how AI can help save lives through successful, long-term interaction, communication, and collaboration between humans and machines. Use estimation approaches for vehicle systems, such as the one detailed here, can be applied more broadly in the context of automated driving and advanced driver assistance systems as a component of developing a risk benefit analysis.

References

[1] L. Fridman, "Human-centered autonomous vehicle systems: Principles of effective shared autonomy," *CoRR*, vol. abs/1810.01835, 2018. [Online]. Available: https://arxiv.org/abs/1810.01835

[2] B. W. Smith, "Sae levels of driving automation," *Center for Internet and Society. Stanford Law School. http://cyberlaw. stanford. edu/blog/2013/12/sae-levels-drivingautomation*, 2013.

[3] L. Fridman, D. E. Brown, M. Glazer, W. Angell, S. Dodd, B. Jenik, J. Terwilliger, J. Kindelsberger, L. Ding, S. Seaman, H. Abraham, A. Mehler, A. Sipperley, A. Pettinato, L. Angell, B. Mehler, and B. Reimer, "MIT autonomous vehicle technology study: Large-scale deep learning based analysis of driver behavior and interaction with automation," *CoRR*, vol. abs/1711.06976, 2017. [Online]. Available: https://arxiv.org/abs/1711.06976

[4] I. Tesla, "Autopilot," https://www.tesla.com/autopilot, 2018, [Online; accessed 05-June-2018].

[5] Wikipedia, "Timeline of Tesla Inc. — Wikipedia, the free encyclopedia," http://en.wikipedia.org/w/index.php?title=Timeline%20of%20Tesla%20Inc.&oldid=823343199, 2018, [Online; accessed 03-June-2018].

[6] L. Fridman, "Tesla vehicle deliveries and projections," https://hcai.mit.edu/tesla-vehicle-numbers, 2018, [Online; accessed 27-Dec-2018].

[7] L. Fridman, "Tesla autopilot miles," https://hcai.mit.edu/tesla-autopilot-miles, 2018, [Online; accessed 27-Dec-2018].