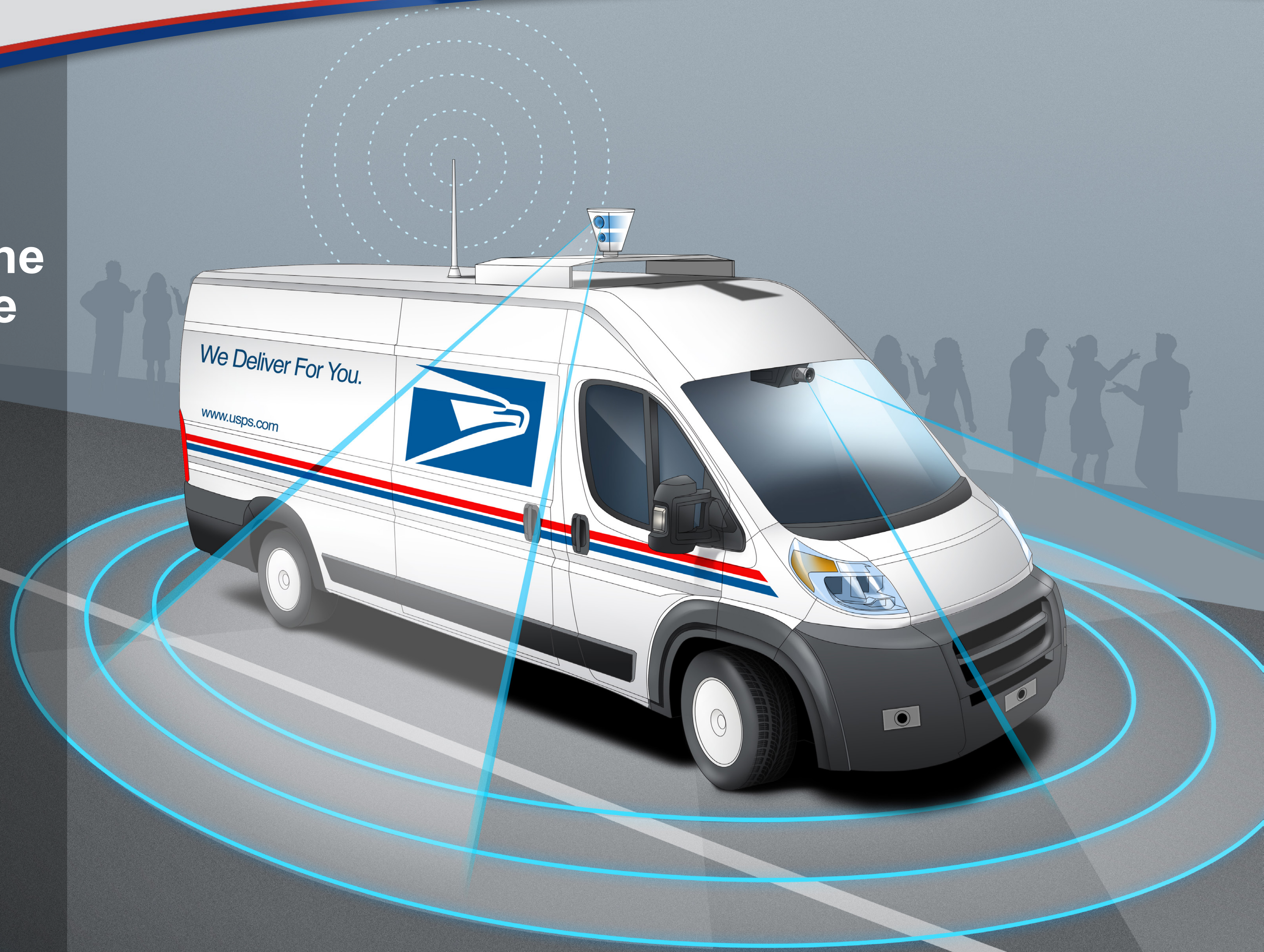
OFFICE OF INSPECTOR GENERAL
UNITED STATES POSTAL SERVICE

Autonomous Vehicles for the Postal Service



RARC Report

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OFFICE OF INSPECTOR GENERAL
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Executive Summary

Autonomous vehicles (AVs) that are able to partially or fully drive themselves could become a reality within the next decade. AV technology promises to increase safety, reduce fuel costs, and improve worker productivity. More importantly, it has the potential to change the nature of the transportation and delivery industries, and to spark new business models.

For the purposes of this paper, “autonomous vehicles” will refer only to cars, trucks, and vans that drive on public roads. Drones, small delivery robots, and wheeled warehouse robots, which have different regulatory and operational considerations, will be the subject of future research.

Some delivery companies, including the U.S. Postal Service (Postal Service), are already researching and testing AV technology. The U.S. Postal Service Office of Inspector General (OIG) set out to examine AV capabilities now and to interview experts about its future potential.

The research suggests that while there remain stumbling blocks to adoption, the impact to the Postal Service will potentially be significant if this promising technology gains traction. To achieve the cost, safety, and productivity benefits while limiting operational and financial risks, we suggest the Postal Service takes a step-by-step approach: test the technology first, gradually automate its vehicles where it makes strategic sense, and refine its AV strategy as the technology, market, regulation, and public perception evolve.

Highlights

Autonomous vehicles (AV) have the potential to begin changing the transportation and delivery industries in the next 5 to 10 years.

AV technology promises to increase driver safety, reduce fuel costs, and boost productivity.

Given its potential benefits, it is worthwhile for the Postal Service to continue experimenting with AV technology, especially in its last-mile delivery and transportation activities.

With the Postal Service already embarking on a multi-year replacement of its vehicle fleet, now may be the right time to lay the building blocks for the future use of AVs in postal operations.

As the Postal Service builds its long-term strategy for testing and deploying AVs, it could consider seven distinct use cases identified by the OIG. These use cases fall into two categories: last-mile delivery and trucking.

For delivery, the OIG identified five use cases:

- **Driving the letter carrier**: Ideal for curbside delivery, the AV would drive itself from mailbox to mailbox, allowing the carrier in the van to prepare the mail for the next address instead of driving.

- **Driverless parking**: The vehicle would park itself as the carrier makes deliveries, eliminating the need to look for parking spots while ensuring the vehicle is out of the way of traffic.
- **Following the carrier**: For walking routes, the vehicle would follow the carrier, reducing walking time to and from the vehicle as well as the heavy loads the carrier has to carry.
- **Picking up more mail from the post office**: When mail from the sorting facility is late or there are too many packages to fit in the vehicle, an AV can be dispatched to bring the items from the post office to the carrier on his route, saving return trips.
- **Mobile parcel locker**: A complete departure from current delivery methods, a fully autonomous mobile locker would remove the carrier from the operation. It would come to the customer when convenient, allowing 24/7, on-demand delivery.

Additionally, the Postal Service could look at AV trucking applications even though currently highway transportation of mail is predominantly contracted out. The benefits of autonomous trucking may be promising enough that the Postal Service could incentivize its contract partners to adopt the technology, favor those who use it, or bring some long-haul transportation in-house. Two main trucking applications emerged from the research:

- **Platooning**: Two or more trucks form single-file “platoons” on the highway, enabled by an electronic system that controls their following distance and possibly steering. Platoons save fuel by optimally reducing wind resistance.
- **Fully autonomous trucks**: A truck that is able to drive either the whole route or the highway portion of the route, exit-to-exit, without a driver present.

None of the seven suggested use cases could be fully deployed today. The technology is not mature enough and the cost is still prohibitive. Federal transportation regulators, though supportive of vehicle autonomy because of its safety benefits, still need to iron out a patchwork of state laws. A skeptical public also needs to be convinced that AVs will be safe to share the road with.

But these seem to be more speed bumps than roadblocks. Given the pace of investment and development, even cautious observers believe the autonomy level of new vehicles will rise over time. This is especially true for transportation and delivery companies that are likely to gain the most from AVs, ranging from incremental time and fuel savings to entirely new and more favorable business models.

To stay competitive, it is worthwhile for the Postal Service, one of the largest fleet operators in the world, to continue testing the technology and refining its transportation strategy. The Postal Service’s current multi-year effort to upgrade its fleet makes this an opportune time to start laying the building blocks for an AV future.

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Observations

Introduction

Self-driving cars, formally known as autonomous vehicles (AVs), have captured imaginations for decades.[1] The past few years have seen that fascination emerge into reality. A major development makes the news seemingly every week, from Uber's driverless taxis in Pittsburgh to Waymo's public test drives in Phoenix.[2]

Although we are still a long way from a time when all, or even most, cars are fully driverless, these developments represent tangible milestones on the path to a driverless future. Businesses have been quick to recognize the benefits. Both the producers of AVs and commercial fleet companies feel they cannot afford to wait and see how the industry plays out — the transportation business model is changing too fast to not stay informed and involved.[3]

Figure 1: Uber's Autonomous Vehicles Take to the Road

Source: Wired.

Although much of the AV conversation focuses on how personal mobility will change, logistics could be profoundly affected as well. UPS, FedEx, DHL, and some foreign posts are already researching and testing the technology. The U.S. Postal Service (USPS) has also taken steps toward a pilot of a semi-autonomous delivery vehicle. This paper seeks to supplement that effort by providing a brief primer on the status of the technology and describing potential use cases for AVs in the delivery and transportation of mail. It will also explain the challenges to implementing these ideas and the potential rewards.

Although "autonomous vehicles" can refer to a variety of moving objects, including cars, trucks, robots, and drones, this paper focuses only on vehicles that use public roads. While drones, delivery robots, and wheeled warehouse robots would be useful for the Postal Service, they have different regulatory and operational considerations and are outside the scope of this paper but will be the subject of further research.

Autonomous Vehicles and How They Work

The Technology

Not all autonomous vehicles are driverless. Rather, "autonomous" refers to a continuum of vehicle intelligence (Figure 2) that includes everything from cruise control and park assist, which are low-automation features common in cars today, to truly driverless vehicles, which are still years away.[4]

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1 For example, a future car with autonomous features was part of the GM Futurama display at the 1939-1940 New York World's Fair. "The Original Futurama," *Wired,* November 27, 2007, https://www.wired.com/2007/11/ff-futurama-original/.

2 Alex Davies, "We Take a Ride in the Self-Driving Uber Now Roaming Pittsburgh," *Wired,* September 14, 2016, https://www.wired.com/2016/09/self-driving-autonomous-uber-pittsburgh/ and John Krafcik, "Apply to Be Part of Waymo's Early Rider Program," *Medium*, April 24, 2017, https://medium.com/waymo/apply-to-be-part-of-waymos-early-rider-program-5fd996c7a86f.

3 For an example of the variety of companies involved in the industry, see CB Insights, "44 Corporations Working on Autonomous Vehicles," May 18, 2017, https://www.cbinsights.com/blog/autonomous-driverless-vehicles-corporations-list/.

4 For more information on the technology of AVs, as well as full descriptions of the levels of automation, please refer to Appendix A.

Figure 2: Continuum of Automation

LEVEL OF AUTOMATION	Level 0 - "No Automation"	Level 1 - "Driver Assistance"	Level 2 - "Partial Automation"	Level 3 - "Conditional Automation"	Level 4 - "High Automation"	Level 5 - "Full Automation"
AVAILABILITY	Since 1880s	Since 1950s	Since 2000s	2018	Next 10 years	10+ years
EXAMPLES	Cars with no automation have been available for over 100 years.	Any car with cruise control, which regulates speed on its own, is at least Level 1.	Higher-end cars that include multiple driver assistance tools, like park assist and lane keep assist, are Level 2.	The 2018 Audi A8 will be able to drive autonomously on the highway at slower speeds.	Not yet available. Numerous carmakers have promised cars that will be fully autonomous on the highway by 2020.	Not yet available. Some Level 5 vehicles will have no steering wheel or pedals.

Source: SAE International, OIG Analysis.

For an AV to function, it must be able to see and understand its surroundings, orient itself in the wider world, and make decisions based on that information. In order to do so, it must have vision sensors, artificial intelligence, and, ideally, 3D image maps.

Vision: The most common sensors that enable AVs to "see" are cameras, radar, and lidar.[5] Each sensor operates in a different way and has its own strengths and weaknesses. For example, radar is good at detecting moving objects but produces low-resolution images. Cameras can read signs but have difficulty seeing in the dark. In many cases, an AV will use more than one sensor type to build redundancy and thus resiliency into the system.

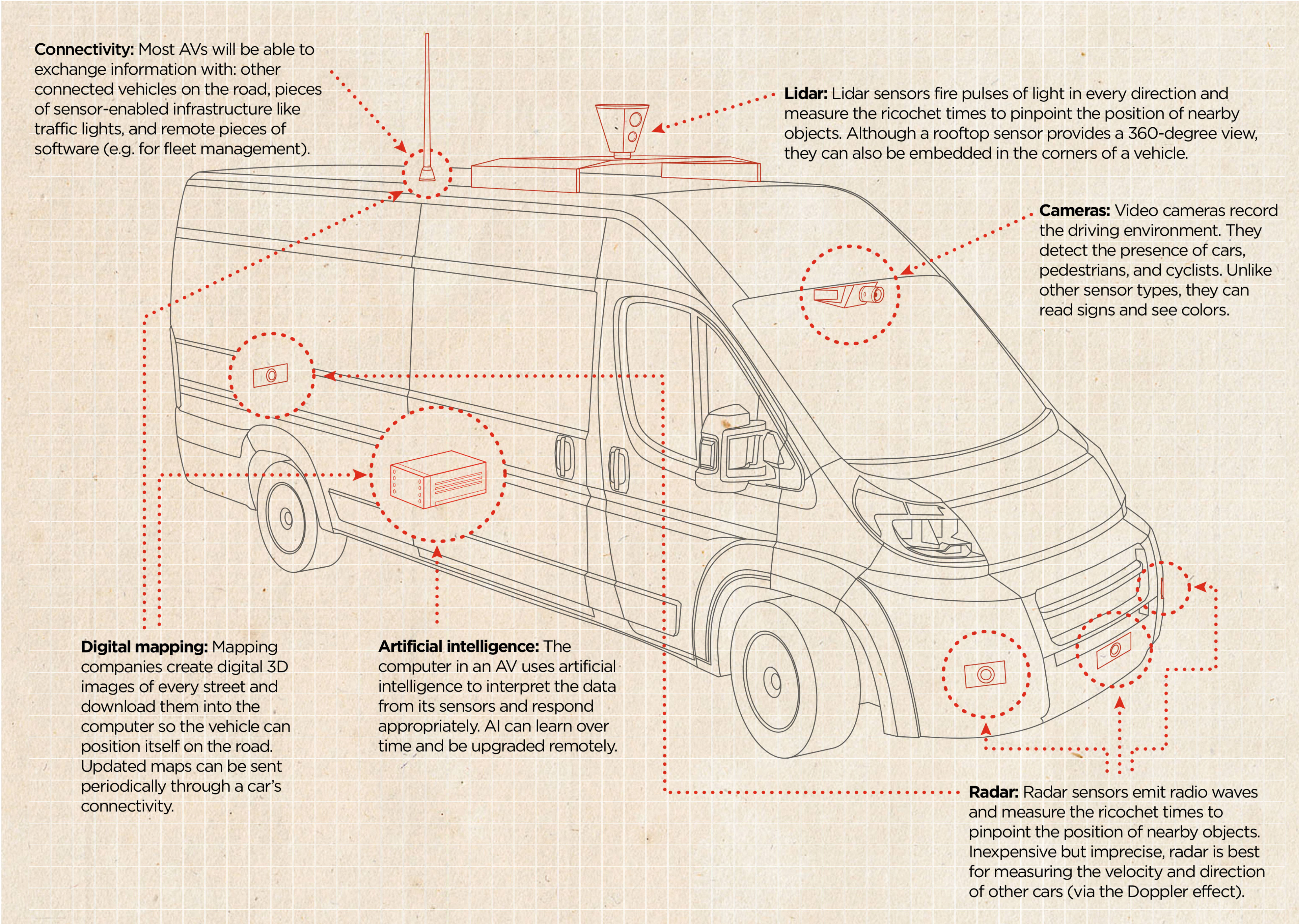
Artificial Intelligence (AI): In order for a car to drive itself, its AI must make a huge number of decisions about how to move. The more autonomous the vehicle, the more its AI needs to be able to handle unusual or dangerous situations. Instructions for how to respond can be manually coded into a computer or, with machine learning, the AI can learn proper driving habits by studying digital recordings of human drivers.

3D Maps: Digital 3D images of the road ahead, which are created in advance by other cars and downloaded into an AV's computer, help the computer interpret real-time sensor data and reduce the number of variables it must process. For instance, sensors may not notice a stop sign if a tree is blocking it, but if the sign appears on the digital map, then the car knows to look for it.

The ability to send and receive data while driving is another feature that, while not a requirement, will allow AVs to make safer, better-informed decisions. They will be able to exchange information with: other cars on the road (vehicle-to-vehicle connectivity); pieces of infrastructure, such as traffic lights, that are equipped with sensors and transmitters (vehicle-to-infrastructure connectivity); or a distant source, like an enterprise's fleet management software.

5 Lidar (Light Detection and Ranging) is similar to radar (Radio Detection and Ranging), but instead of bouncing radio waves off objects to determine their location and movement, lidar uses beams of light.

Figure 3: Sensors on an Autonomous Vehicle



Source: The Economist, OIG Analysis.

"There is no doubt that self-driving vehicles will change the world of logistics… the question is no longer 'if' but rather 'when' autonomous vehicles will drive onto our streets and highways."
-DHL Trend Report, "Self-Driving Vehicles in Logistics"

Impact on Logistics

While the global AV discussion has focused on improvements to personal mobility, road safety, and driver convenience, the technology has clear implications for logistics in both delivery and trucking. The trucking industry alone could see potential savings in labor, fuel, and accident costs of $168 billion annually.[6] Logistics companies, including FedEx and UPS, are looking into the benefits of the technology.[7]

AVs also have the potential to transform last-mile delivery. Google has applied for a patent for an "autonomous delivery platform" — essentially a driverless mobile parcel locker.[8] Parcel delivery company DPD Germany put forth a similar idea in a recent white paper on AVs.[9] Swiss Post is even piloting two autonomous shuttle buses. The testing of this shuttle gives Swiss Post experience with the technology, in case it decides to use AVs for delivery in the future.[10]

These companies are mostly in the ideation and research phase — many of their ideas for potential applications have not even made it to pilots yet. However, some industry experts think commercial applications will develop faster than consumer applications, due to the financial promise of increased labor productivity, fuel savings, and improved safety.[11]

Benefits

Safety

Government officials are interested in AVs' potential to improve road safety.[12] Ninety-four percent of crashes in the U.S. are caused by human choice or error — and are therefore preventable. Research has estimated that AVs could reduce the number of crashes by 90 percent by overcoming drunk, distracted, or otherwise poor driving.[13] And while even attentive human drivers often repeat driving mistakes, many AVs learn from previous experiences and do not make the same mistake twice.[14]

The Postal Service, which employs hundreds of thousands of drivers, stands to benefit greatly from a drop in the accident rate. In 2016, postal vehicles were involved in about 30,000 accidents.[15] While the majority did not result in any injury, an average of 12 postal employees are killed in motor vehicle accidents annually.[16] Accident costs, including vehicle repair, worker's compensation, employee lost time, increased insurance premiums, and lawsuit settlements, can quickly add up. In fiscal year (FY) 2016, the Postal Service paid about $67 million in repair and tort costs related to motor vehicle accidents.[17]

6 The savings are expected to come from labor ($70bn), fuel efficiency ($35bn), productivity ($27bn) and accidents ($36bn). Morgan Stanley, *Autonomous Cars: Self-Driving the New Auto Industry Paradigm,* November 6, 2013, http://orfe.princeton.edu/~alaink/SmartDrivingCars/PDFs/Nov2013MORGAN-STANLEY-BLUE-PAPER-AUTONOMOUS-CARS%EF%BC%9A-SELF-DRIVING-THE-NEW-AUTO-INDUSTRY-PARADIGM.pdf.
7 FedEx has announced that it is pursuing fully autonomous trucks. Elizabeth Woyke, "FedEx Bets on Automation as it Prepares to Fend Off Uber and Amazon," *MIT Technology Review,* February 3, 2017, https://www.technologyreview.com/s/602896/fedex-bets-on-automation-as-it-prepares-to-fend-off-uber-and-amazon/.
8 Mike Murphy, "Google Wants to Deliver Packages from Self-Driving Trucks," *Quartz,* February 9, 2016, https://qz.com/613277/google-wants-to-deliver-packages-from-self-driving-trucks/.
9 DPD Group, *Parcel Delivery by Driverless Vehicles,* November 2016, https://www.dpd.com/de_en/content/download/11649/365492/file/20161103_DPD_Autonomous_Driving_Scenarios.pdf.
10 Interestingly, the shuttle manufacturer has suggested that a mobile parcel locker could be combined with the shuttle. Martina Mueggler, Leader of Innovations and Product Management at PostAuto Schweiz AG, in discussion with the authors, February 28, 2017. For more information on Swiss Post's autonomous shuttle pilot, see Appendix C.
11 Morgan Stanley, 2013, pp. 11, 85.
12 Automobile accidents caused 35,000 deaths in 2015. For every fatality, another eight people were hospitalized and 100 were treated and released from emergency rooms. The annual cost of roadway crashes to the U.S. economy is in the hundreds of billions of dollars. McKinsey & Company, "Ten Ways Autonomous Driving Could Redefine the Automotive World," June 2015, http://www.mckinsey.com/industries/automotive-and-assembly/our-insights/ten-ways-autonomous-driving-could-redefine-the-automotive-world.
13 U.S. Department of Transportation, *Federal Automated Vehicles Policy: Accelerating the Next Revolution in Roadway Safety,* September 2016, https://www.transportation.gov/AV/federal-automated-vehicles-policy-september-2016, p. 5, and McKinsey & Company, 2015.
14 U.S. Department of Transportation, 2016, p. 5.
15 This figure is up significantly from the 20,000 accidents per year in 2010 and 2011. Increasing time pressure on drivers and a reliance on non-career employees, who often lack experience with postal vehicles because of their high turnover rate, may be to blame.
16 Average based on Bureau of Labor Statistics Data 2011-2015 using "Postal Service Workers" occupational code, at https://www.bls.gov/iif/.
17 United States Postal Service, Financial Performance Report.

Fuel and Vehicle Cost Savings

Fuel savings is another major benefit, particularly when it comes to trucking. Since fuel expenses make up more than one-third of the total expense of operating a truck fleet, companies are very interested in obtaining even a 1 or 2 percent gain in fuel efficiency.[18] Some trucking applications can generate up to a 21 percent gain in fuel efficiency.[19] Since the Postal Service spent over $570 million on diesel fuel for network transportation in FY 2016, even small efficiencies could generate millions of dollars in savings.[20]

It is possible that even AVs on local streets, including delivery vehicles, would experience some fuel savings due to reductions in hard braking and acceleration. There are few definitive metrics on the fuel efficiency of autonomous cars, however. Different studies suggest that fuel usage could eventually be cut by up to one-half under certain specific conditions. One study suggested that an AV operating at peak driving efficiency could cut fuel consumption in half during heavy traffic congestion, but also noted that such instances are rare.[21] Another study estimated that consumption could be reduced by 23-39 percent under normal driving conditions once AVs become common, due to smoother traffic flows.[22] The U.S. Postal Service spent $359 million on delivery route fuel in FY 2016, so an increase of even 1 percent in fuel efficiency during non-highway driving would have saved the Postal Service $3.6 million in FY 2016.[23]

Automated vehicles would achieve other cost savings for the Postal Service as well. AVs that can drive themselves back to the post office to pick up more packages (see page 14 for details) would mitigate the need to buy bigger, more expensive, less fuel-efficient vehicles. Furthermore, if AVs could serve multiple routes or cut delivery times enough to allow for route consolidation, fewer total vehicles would be needed.[24] However, these AVs might wear out faster due to increased use.

Labor Productivity Increases

In the short-term, this technology will make workers more productive, enable them to take on more duties, and lower driving-related stress.

For trucking, there may be an ongoing role for a freight professional in the truck, although the nature of the job may change.[25] For example, he could perform administrative tasks, customer service calls, or route planning. He could also sleep or relax in the cab, allowing him to comply with national regulations that mandate rest breaks, without stopping his journey.[26] Long trips would be completed faster, which would ameliorate the national shortage of truck drivers by getting existing drivers back on the road sooner.[27]

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18 American Trucking Associations Technology and Maintenance Council, *Automated Driving and Platooning Issues and Opportunities,* September 21, 2015, http://orfe.princeton.edu/~alaink/SmartDrivingCars/ITFVHA15/ITFVHA15_USA_FutureTruck_ADP_TF_WhitePaper_Draft_Final_TF_Approved_Sept_2015.pdf.
19 Bruce Gaudet, *Review of Cooperative Truck Platooning Systems*, prepared for Transport Canada, September 3, 2014, https://www.tc.gc.ca/eng/programs/environment-etv-menu-eng-2994.html.
20 U.S. Postal Service Office of Inspector General, "Fuel Consumption and and Cost Risk Mitigation," Report No. NL-AR-17-004, April 24, 2017, https://www.uspsoig.gov/sites/default/files/document-library-files/2017/NL-AR-17-004.pdf, p. 6.
21 Zia Wadud, Don MacKenzie, and Paul Leiby, "Help or Hindrance? The Travel, Energy, and Carbon Impacts of Highly Automated Vehicles," *Transportation Research Part 1*, Vol. 86, 2016, http://www.sciencedirect.com/science/article/pii/S0965856415002694.
22 Daniel J. Fagnant, Kara M. Kockelman, and Prateek Bansal, "Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers, and Policy Recommendations for Capitalizing on Self-driven Vehicles," *Transportation Research Part A*, No. 77:167-181, 2015, http://www.caee.utexas.edu/prof/kockelman/public_html/TRB14EnoAVs.pdf, p. 4.
23 U.S. Postal Service, *2016 Report on Form 10-K,* http://about.usps.com/who-we-are/financials/10k-reports/fy2016.pdf, p. 30.
24 USPS has expressed that it is interested in AVs, at least partially, because of this potential to consolidate routes. Han Dinh, Director of Vehicle Engineering at USPS, in discussion with the authors, March 22, 2017.
25 Stephen Boyd, Co-founder and Vice President of External Affairs at Peloton Technology, in discussion with the authors, March 24, 2017.
26 U.S. Department of Transportation, "Summary of Hours of Service Regulations," March 9, 2017, https://www.fmcsa.dot.gov/regulations/hours-service/summary-hours-service-regulations.
27 In 2015, the industry was short 48,000 drivers. Hours-of-service rules, which dictate how long a trucker may drive before taking a mandatory rest period, further limit driver availability and capacity. American Trucking Associations, "Reports, Trends, & Statistics," http://www.trucking.org/News_and_Information_Reports_Driver_Shortage.aspx.

For delivery, AVs could assist carriers by reducing the load they have to carry, the distance they have to walk, and the time they have to spend parking and driving. Carriers can collect mail for the next delivery or walking relay while the AV drives itself.[28] By saving time on each delivery or on other tasks, routes will be completed faster, enabling the Postal Service to either consolidate routes or have carriers perform additional services such as postal services, government services, or other miscellaneous services.[29]

Even if the Postal Service chooses not to expand the carrier's role or consolidate routes, there is still value in completing routes on time. Letter carriers have been increasingly unable to finish their routes before dark, especially with the increasing volume of packages. AVs can ease their burden while avoiding expensive overtime pay.

Improved Brand Image

Testing and using AVs would be a highly visible way for the Postal Service to demonstrate an interest in innovative technologies in its core business and be viewed as an innovative company.[30] Swiss Post has found the press coverage of its autonomous bus pilot to be better than any marketing campaign.[31]

There is also brand value in becoming more environmentally friendly. AVs can help by not only reducing fuel consumption, as mentioned above, but also reducing urban congestion. Anyone who lives in a city is familiar with double-parked delivery vans blocking narrow streets. An AV van could move out of the way to avoid causing a traffic jam, or it might be a smaller vehicle that is less obstructive.[32]

AVs would also help make the Postal Service more responsive to changing customer preferences. Driverless postal vehicles could deliver around the clock, on-demand, and sometimes same-day. AVs could also enable the Postal Service to offer new services to local governments and private companies. For example, many AV companies want to create digital 3D maps of every road in the U.S., then update the maps regularly to note new construction, potholes, and buildings.[33] If the Postal Service was using AVs for delivery, the sensors would automatically map the streetscape every day; that data could be sold to the mapping companies.[34]

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28 A walking relay, also called a "park and loop," is when a carrier parks, delivers mail on foot down one side of the street, crosses, and delivers mail down the other side on the way back to the truck.

29 For example, carriers could increase the time spent generating sales leads, an activity they already conduct through programs such as Customer Connect and Rural Reach. U.S. Postal Service, *About: Customer Development*, https://about.usps.com/strategic-planning/cs09/CSPO_09_070.htm. Carriers could also collect data on behalf of local governments, such as identifying vacant properties, or expand community services such as their Carrier Alert program, where city carriers monitor the well-being of elderly and disabled customers and alert the appropriate local authority of problems. The OIG has proposed both local government services and an expanded role for the Postal Service to offer health services, particularly to the elderly. OIG, *The Postal Service's Role in Delivering Wellness Services and Supplies,* Report No. RARC-IB-15-004, July 22, 2015, https://www.uspsoig.gov/sites/default/files/document-library-files/2015/rarc-ib-15-004_the_postal_services_role_in_delivering_wellness_services_and_supplies_0.pdf and OIG, *The Postal Service and Cities: A "Smart" Partnership,* RARC-WP-16-017, September 26, 2016, https://www.uspsoig.gov/sites/default/files/document-library-files/2016/RARC-WP-16-017.pdf.

30 "Innovative" has been identified as an aspirational brand characteristic for the Postal Service. The OIG's own survey research shows that respondents would feel more positively about the Postal Service's brand if it were to use AVs. OIG, *The Value of the U.S. Postal Service Brand,* Report No. RARC-WP-15-005, January 28, 2015, https://www.uspsoig.gov/sites/default/files/document-library-files/2015/rarc-wp-15-005_0.pdf and OIG, *Public Perception of Self-Driving Vehicles for Logistics Applications in the United States*, Report No. RARC-WP-17-011, September 5, 2017, https://www.uspsoig.gov/sites/default/files/document-library-files/2017/RARC-WP-17-011.pdf.

31 Thierry Golliard, Head of Open Innovation and Venturing at Swiss Post, in discussion with the authors, March 30, 2017.

32 Jim Bruce, Senior Vice President of Corporate Public Affairs at UPS, in discussion with the authors, April 6, 2017.

33 Companies like Velodyne, Mobileye, and Carmera are interested in leveraging delivery fleets to improve AV maps. Erin Griffith, "Meet Carmera, A Startup Using Delivery Fleets to Create 3D Maps of Cities," *Fortune,* June 5, 2017, http://fortune.com/2017/06/05/carmera-maps-funding/; Harris Wang, Velodyne, in discussion with the authors, March 10, 2017; and Neal Boudette, "Building a Road Map for the Self-Driving Car," *The New York Times,* March 2, 2017, https://www.nytimes.com/2017/03/02/automobiles/wheels/self-driving-cars-gps-maps.html?WT.mc_id=SmartBriefs-Newsletter&WT.mc_ev=click&ad-keywords=smartbriefsnl&_r=2.

34 This mapping could be done using lidar, where there are no faces, license plates, or other privacy red flags.

Stumbling Blocks

Maturity of the Technology

Fully driverless AVs will not be available in the next five or likely even 10 years. The millions of miles in testing that companies like Waymo and Tesla have completed so far represent only a fraction of the potentially *billions* of miles that AVs will have to drive in order to prove that they are as capable as human drivers.[35] Furthermore, the industry is still perfecting the foundational pillars of the technology; sensors still have problems seeing through bad weather, for instance. The condition of the road infrastructure can also hinder AV performance; lane markings and signage need to be present and unobscured for AV sensors to notice them.

Companies are hopeful that they can soon resolve the remaining technical issues. And while fixing the road infrastructure is out of the hands of the private sector, technological sophistication can overcome most of those problems. As a result, even pessimists accept that AVs are an inevitability; the only debate is over when. Nearly all major auto manufacturers have promised to put an AV on the market by 2021.[36] Tech companies have set even bolder timelines.[37] About half of supply chain and logistics professionals expect driverless trucks in their operations by 2025.[38] On the other hand, academics and consultants tend to be more cautious in their projected timelines.

Long-Term Labor Implications

Any near-term reduction in the postal workforce through route consolidation would likely happen slowly, through attrition.[39] However, there are long-term labor implications to consider:

- **Large-scale job loss:** Almost half of jobs in the U.S. are "susceptible to computerization within 20 years."[40] Once driverless vehicles emerge, at maturity they could replace letter carriers on a large scale. This possibility could make employees hesitant to accept the technology. Furthermore, it could be politically difficult for the Postal Service to make drastic cuts to its workforce. However, a machine does not easily replace the institutional knowledge, judgement, and human contact that carriers can provide.[41] The threat of eventual job loss also extends to trucking, especially long-haul. This is less of an issue for the Postal Service since most of its long-haul truck drivers are currently contractors.

- **The changing nature of work:** Carriers would need to be trained on proper usage of AVs. The Postal Service would need to work with unions and employees to effectively deploy the new technology, as it has with the introduction of other new technology, such as its handheld scanners.[42] Carriers may also see their role become more complex due to the potential offering of new services. Additionally, even though driving jobs themselves may decline, AV technology will likely create new jobs in the areas of maintenance, technical support, and fleet management.

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35 Waymo has already driven AVs more than three million miles in road tests, and Tesla drivers have put over 300 million miles on Autopilot. Kerry Wu, "The State of Auto Tech," Webinar, May 24, 2017, slide 50, and Rand Corporation, "Driving to Safety: How Many Miles of Driving Would it Take to Demonstrate Autonomous Vehicle Reliability," 2016, http://www.rand.org/content/dam/rand/pubs/research_reports/RR1400/RR1478/RAND_RR1478.pdf.

36 See, for example Matthew J. Belvedere, "Ford Aims for Self-Driving Car with no Gas Pedal, no Steering Wheel in 5 years, CEO says," *CNBC,* January 9, 2017, http://www.cnbc.com/2017/01/09/ford-aims-for-self-driving-car-with-no-gas-pedal-no-steering-wheel-in-5-years-ceo-says.html.

37 Tesla started including self-driving hardware in models last year, with plans to activate the software remotely as soon as it has done enough testing. Tesla, "All Tesla Cars Being Produced Now Have Full Self-Driving Hardware," 2016, https://www.tesla.com/blog/all-tesla-cars-being-produced-now-have-full-self-driving-hardware. Lyft claims that within 5 years, a majority of its rides will be in fully autonomous cars. John Zimmer, "The Third Transportation Revolution: Lyft's Vision for the Next Ten Years and Beyond," *Medium,* September 18, 2016, https://medium.com/@johnzimmer/the-third-transportation-revolution-27860f05fa91.

38 eft, "Innovation + Automation Infographic," http://img03.en25.com/Web/FCBusinessIntelligenceLtd/%7B804a657d-1ec4-48cd-b73f-06e8c2fe40e0%7D_1875_EfTransport_Innovation_Infographic_V1.pdf.

39 Unions protect career carriers from involuntary layoffs. National Rural Letter Carriers' Association, "National Agreement between the United States Postal Service and the National Rural Letter Carriers' Association 2015-2018," *The National Rural Letter Carrier: Special Contract Edition,* 115, No. 10a, 2015, https://ruralinfo-4603.kxcdn.com/wp-content/uploads/2016/11/2015-2018-contract.pdf and National Association of Letter Carriers, "Tentative National Agreement is Reached," May 12, 2017, https://www.nalc.org/news/nalc-updates/tentative-national-agreement-is-reached.

40 Kevin Desouza, David Swindell, Kendra L. Smith, Alison Sutherland, Kena Fedorschak, and Carolina Coronel, "Local Government 2035: Strategic Trends and Implications of New Technologies," *Issues in Technology Innovation,* No. 27, May 2015, https://www.brookings.edu/wp-content/uploads/2016/06/desouza.pdf, p. 8.

41 Carriers can interact with customers, may be better able to deal with the unexpected, and often have deep knowledge of their routes, including mailbox locations and customer preferences. Jim Holland, Research Director at National Association of Letter Carriers, in discussion with the authors, April 19, 2017.

42 For example, the Postal Service would need to consult the unions on how to best design the vehicles for ergonomic mail delivery and how to train employees to use them. Holland, 2017.

- **Privacy concerns:** Carriers may be wary that the sensors and connectivity in their AVs allow supervisors to monitor their activities and may be concerned about data misuse. For example, supervisors might not appreciate the reasons that an employee might not behave in a "programmed" way.[43] Nevertheless, research shows that once employees start using the technology, they realize that it helps improve their driving.[44] Such information could also prove that they are not at fault in a crash.

Public Perception

Surveys show that the public is not convinced that AVs will improve the driving experience or reduce traffic congestion or accidents.[45] In a survey conducted by the U.S. Postal Service Office of Inspector General (OIG), people expressed concern about device malfunction and safety, which aligns with what AV companies are hearing anecdotally from customers.[46] Since people tend to be less forgiving of accidents caused by machines than those caused by humans, fear of malfunction could be an impediment to adoption and acceptance.

As with many new technologies, people who are more familiar with AV technology tend to be more excited and less worried.[47] As the public gains exposure to AVs, opinions will likely trend towards favorability. This holds true for logistics applications as well. The OIG survey similarly found that once people are exposed to the idea of AVs in logistics, their comfort and enthusiasm increases.[48] Respondents, however, did not trust the Postal Service to implement the technology successfully, in comparison to other brands.[49]

Capital Investment

Making an up-front investment in AVs is of course a prerequisite to reaping their benefits. Low-level automation tools are already available at reasonable price points. Driver assistance packages such as the Honda Sensing system can be added for $1,000.[50] Tesla's Enhanced Autopilot, capable of hands-free highway driving, can be added for about $5,000.[51]

Fully autonomous vehicles, on the other hand, can cost hundreds of thousands of dollars to build because the price of advanced components remains quite high.[52] Luckily, prices have been coming down — lidar and mapping modules have become 90 percent cheaper over the last few years.[53] If these trends continue, the prediction that self-driving technology will add only $7,000 to $10,000 to the purchase price of a vehicle in 2025 (and only $3,000 in 2035) seems more likely.[54]

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43 Ibid.
44 Intel, *Intelligent Fleet Management,* 2015, https://www.intel.com/content/dam/www/public/us/en/documents/white-papers/atom-e3800-intelligent-fleet-management-paper.pdf, p. 6.
45 Only 32 percent of respondents felt that AVs would improve the driving experience; almost half responded that it would *not* improve the driving experience. Respondents are further concerned about potential job loss and privacy violations. Timothy B. Lee, "We Polled Americans About Self-Driving Cars. Here's What They Told Us," *Vox,* August 29, 2016, https://www.vox.com/2016/8/29/12647854/uber-self-driving-poll.
46 OIG, *Public Perception of Self-Driving Vehicles for Logistics Applications in the United States;* Aravind Kailas, Principal Technology Planner at Volvo, in discussion with the authors, April 18, 2017; and Tim Wong, NVIDIA, in discussion with the authors, May 18, 2017.
47 Attitudes often differ drastically by age. A slight majority of respondents under 30 are excited by the future of self-driving cars, whereas just 19 percent of respondents over 65 said they are excited about self-driving cars. Lee, 2017.
48 OIG, Public Perception of Self-Driving Vehicles for Logistics Applications in the United States, slides 10-11.
49 Ibid, slide 14.
50 Kristen Hall-Geisler, "2016 Honda Civic: Autonomous Features for $20K," *Techcrunch,* March 18, 2016, https://techcrunch.com/2016/03/18/2016-honda-civic-autonomous-features-for-20k/.
51 IHS Markit, "Tesla to Build All Models with Level 5 Autonomous Technology; Full Self-Driving Capability to Cost USD 8,000," October 20, 2016, http://blog.ihs.com/tesla-to-build-all-models-with-level-5-autonomous-technology-full-self-driving-capability-to-cost-usd8000. Tesla's autonomous systems do not use lidar, which helps keep the cost low. Tesla, "Full Self-Driving Hardware on All Cars," https://www.tesla.com/autopilot.
52 Steve LeVine, "What it Really Costs to Turn a Car into a Self-Driving Vehicle," *Quartz,* March 5, 2017, https://qz.com/924212/what-it-really-costs-to-turn-a-car-into-a-self-driving-vehicle/.
53 Waymo announced early this year that they are reducing the price of their lidar by 90 percent compared to what it was just a few years ago; Velodyne has likewise lowered their prices for lidar sensors and mapping. Danielle Muoio, "Google Just Made a Big Move to Bring Down the Cost of Self-Driving Cars," *Business Insider,* January 8, 2017, http://www.businessinsider.com/googles-waymo-reduces-lidar-cost-90-in-effort-to-scale-self-driving-cars-2017-1 and Wang, 2017.
54 IHS Markit, "Self-Driving Cars Moving into the Industry's Driver's Seat," January 2, 2014, http://news.ihsmarkit.com/press-release/automotive/self-driving-cars-moving-industrys-drivers-seat.

Regulatory Uncertainty

So far, regulators have not intervened much in the development of AV technology, which they believe will bring benefits to society. There are currently no federal laws specifically regarding AVs, and only about half of states have regulated them.[55] This has created uncertainty, especially since state regulations often differ from one another.[56] Once AVs are ready for mass production, unless ironed out through legislation or litigation, this patchwork will become a problem. It will be difficult to sell a vehicle that cannot legally cross the border from Kansas to Colorado. As the operator of a national fleet, any uncertainty or state-to-state variation would negatively impact how the Postal Service could deploy the technology.

Federal standards can clarify AVs' future and allow commercial fleet operators, including the Postal Service, to begin adoption. The biggest step in that direction so far was a set of guidelines issued by the Department of Transportation (DOT) in September 2016. Although it did not lay out many specific requirements, it did suggest a loose framework, while simultaneously proclaiming DOT's support for AVs as a means of reducing road fatalities.[57]

On July 19, a draft proposal of an AV bill was passed out of subcommittee on a bipartisan basis by the House Energy and Commerce Committee. If it is eventually signed into law, the Highly Automated Vehicle Testing and Deployment Act of 2017 would give DOT regulations precedence over state regulations, and would greatly increase the number of AVs that companies are allowed to test.[58]

Possible Postal Applications of AV Technologies

The potential applications for AVs operating on public roads by the Postal Service fall into two main categories: last-mile delivery and trucking. This section presents seven use cases — five for delivery and two for trucking. These seven are not an exhaustive list, nor do they necessarily reflect the Postal Service's objectives for AVs. Rather, they are those that we considered the most impactful, based on our review of the technology and conversations with experts.

Delivery

Delivery is the core function of the Postal Service, making it a natural application for AVs. Delivery applications of AVs are generally more complex than highway trucking ones. Delivery vehicles must contend with other drivers, pedestrians, and cyclists, obey signs and signals, and cross intersections. To navigate such a dynamic setting, an AV must be able to react properly to all of those variables within fractions of a second. In addition, it must be able to bring the mail to every address on its route. This involves frequent stops and requires precise coordination with the letter carrier (if one is present).

Because of this complexity, few AV test pilots for delivery currently exist. However, logistics companies are actively researching how to apply the technology to delivery. After reviewing industry activity, we identified five delivery use cases of potential interest to the Postal Service:

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55 National Conference of State Legislatures, "Autonomous Vehicles: Self-Driving Vehicles Enacted Legislation," June 26, 2016, http://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx.

56 Some states, like Pennsylvania, Virginia, Nevada, California, and Michigan, welcome AV testing. Others have yet to make any rules for or against AV use. Even some localities might attempt to ban the technology. San Francisco County Supervisor Aaron Peskin said earlier this year that "San Franciscans are not guinea pigs and our public streets aren't experimental test labs." Stephanie Mlot, "Bill Would Fine Illegal Autonomous Vehicles $25K Per Day," *PC Mag*, January 6, 2017, http://www.pcmag.com/news/350859/bill-would-fine-illegal-autonomous-vehicles-25k-per-day.

57 It did include a safety standard and also affirmed the rights of states to register AVs, regulate their insurance, determine liability in an accident, and enforce traffic law. U.S. Department of Transportation, "Automated Vehicles," https://www.nhtsa.gov/technology-innovation/automated-vehicles.

58 Colin Wood, "Federal bill on self-driving vehicles advances with increase to national deployment cap, ban on state regulations," *StateScoop*, July 19, 2017, http://statescoop.com/house-committee-passes-self-driving-vehicle-proposal-to-raise-the-national-deployment-cap-and-stop-states-from-regulating.

- Autonomous vehicle drives the carrier.
- Autonomous vehicle parks itself.
- Autonomous vehicle follows the carrier.
- Autonomous vehicle picks up more mail from the post office.
- Mobile parcel locker.

Autonomous vehicle drives the carrier

How it works: In this application, the letter carrier would still be present in the vehicle and make deliveries as normal, but the vehicle would handle most of the driving responsibilities (although the carrier may need to take control at times if the vehicle is not fully autonomous). This application enables the carrier to complete small tasks while the vehicle is in motion, both during the commute to and from the delivery route and throughout the day. The trip between the post office and the route may take 10-20 minutes, depending on traffic and distance. The carrier could use that time to complete administrative or sorting work that otherwise would be done prior to departure, or close-out work at the end of the day.

During the route, the AV moves the carrier from mailbox to mailbox with no human intervention. It pulls up to the GPS location of the house and, using its sensors to identify the mailbox, stops in front of it. Because the carrier is no longer responsible for driving, he can use the quick trips between boxes to gather the mail from the mail trays for the next address, which today is done only after the vehicle stops, adding about one minute to a route for every 10 stops.[59] In addition to saving time gathering the mail, AVs would virtually eliminate the time that carriers need to transition from driving mode — hands on the wheel, feet on the pedals, eyes on the road — to delivery mode, and back.

The time between stops could also be used for other tasks. For instance, he could fill out the “Sorry We Missed You” slip before attempting delivery of a Certified Mail piece to a home where he knows from experience that the resident is unlikely to be present. After knocking on the door to confirm that no one is home, he sticks the slip on the door and moves on with no delay.

Type of delivery: This application is best suited for curbside delivery, such as rural and suburban routes, where the carrier spends most of the time in the vehicle, although it could be used on “park and loop” city routes as well. Carriers could gather the mail for the next loop while the vehicle drives them to the next parking spot.

Current testing: The Postal Service is pursuing an AV application similar to the model described above. In partnership with the University of Michigan, it is building a prototype to test on rural routes and has a pending patent on the related technology.[60] The carrier would sit behind the wheel, sort mail on the move, and deliver through the window while the vehicle drives, thereby achieving small but cumulatively significant time savings. As currently envisioned, the prototype is only partially autonomous, meaning the driver must be ready to assume control at all times. If tests are successful, the Postal Service hopes to deploy the vehicle on 28,000 rural routes by 2025 and eventually explore other delivery applications.[61]

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59 Carriers usually have separate trays for: mail sorted by machines to delivery point sequence, additional letters and flats hand-sorted at the beginning of the morning, and Every Door Direct Mail advertisements. Gathering the mail for each delivery point from these trays adds 2-10 seconds to each stop depending on the volume of mail. Using an average of 6 seconds, this adds about 1 minute to a route for every 10 stops.

60 The Postal Service selected rural routes because rural roads are less congested, have fewer sensory inputs, and are therefore more forgiving of an imperfect AV model. Dinh, 2017.

61 For more information on the Postal Service’s current efforts to test, pilot, and build an autonomous vehicle for delivery, please refer to Appendix B.

Autonomous vehicle parks itself

How it works: Long-distance walking is an inefficiency that occurs when a carrier cannot find parking near the delivery point.[62] An AV that finds its own parking spot would reduce wasted time while alleviating the physical burden of carrying heavy mailbags and parcels long distances.

Current parking assist tools, which are found in many passenger cars, enable vehicles to parallel park themselves when placed in front of a parking spot. This would save carriers a minute or two. The real gains would come from an AV that could drop the carrier off at a delivery point and then move itself down the block until it found a place to wait. The carrier could make his deliveries before walking to the vehicle (removing some of the convenience factor) or summoning it with an app, whereupon it pulls out of the parking spot and comes to him.

Type of delivery: This feature would be most beneficial for inner-city delivery where streets are crowded and parking is hard to find.

Current testing: We did not find evidence of a logistics company testing this feature. DPD Germany explored the idea in their white paper on AV applications, and found that self-parking vans could save its carriers 40 minutes a day.[63] Low-level park assist tools have been available since at least 2003, though.[64]

Autonomous vehicle follows the carrier

How it works: Today, when a carrier has to deliver several packages along a single walking relay and cannot carry them all in one trip, he must either make multiple trips to the vehicle to retrieve them, or make a round of package deliveries in the van before going back to deliver the mail on foot. An AV that could slowly follow him as he walks, safely avoiding obstacles without any human intervention, would make such inefficient activity unnecessary. With the vehicle always nearby, packages would only have to be carried a short distance, reducing fatigue and potentially lowering the chance of injury. And he would no longer need to waste time walking back to a parked vehicle.

Type of delivery: This solution would work well in areas where other cars can go around the AV, such as strip malls, suburbs, and apartment complexes with several buildings. It would also be useful for routes where a street only has addresses on one side as it would eliminate "deadhead time" — the time wasted walking back to the vehicle without making deliveries. It would be less feasible on narrow or busy city streets, unless the AV could get out of the way of traffic.

Current testing: In 2011, Volkswagen created a prototype of a carrier-following delivery van for Deutsche Post.[65] This vehicle does not appear to have been further developed, although DHL mentioned the value of such a vehicle in their 2014 trend report on AVs.[66] DPD Germany likewise researched a concept vehicle that follows a carrier, although their vision is a smaller robot-like vehicle that follows the carrier on the sidewalk.[67]

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62 DHL Trend Research, *Self-Driving Vehicles in Logistics: A DHL Perspective on Implications and Use Cases for the Logistics Industry,* 2014, http://www.dhl.com/content/dam/downloads/g0/about_us/logistics_insights/dhl_self_driving_vehicles.pdf, p. 31.
63 DPD Group, 2016.
64 "Toyota Unveils Car that Parks Itself," *CNN,* September 1, 2003, http://www.cnn.com/2003/TECH/ptech/09/01/toyota.prius.reut/index.html.
65 Ariel Schwartz, "Going Postal: Volkswagen's Autonomous Mail Van Follows Mail Carriers," *Fast Company,* November 21, 2011, https://www.fastcompany.com/1678875/going-postal-volkswagens-autonomous-mail-van-follows-mail-carriers.
66 DHL Trend Research, 2014, p. 31.
67 DPD Group, 2016.

Autonomous vehicle picks up additional mail from the post office

How it works: There are times when a carrier must interrupt his route to pick up more mail and packages for delivery. This primarily happens for two reasons:

- *Too many packages*: On some days, a route has so many packages that they cannot all fit in the delivery vehicle.[68]
- *Late-arriving mail from the plant*: Sometimes the morning's mail shipment from the sorting center to the post office is delayed. Carriers may begin to deliver the mail they have before returning to pick up the late-arriving mail.

An AV could make those extra pickups without the carrier. It could travel back to the post office, get loaded by another employee, and drive back to meet the carrier. Alternatively, a different AV could be loaded with the items and dispatched from the post office to the delivery route to make the drop off. Both options would allow the carrier to continue delivering mail or take a lunch break. They would be spared the extra trip, as would postal managers, who sometimes travel out to the routes to drop off mail and packages with carriers.

Type of delivery: This application would be suitable to all types of delivery, as no route is immune from delayed mail or too many packages. Since the AV is expected to navigate independently, it would work in both urban and rural areas.

Current testing: DHL mentioned the concept of a support vehicle that is dispatched to a route in progress in its paper.[69] The Postal Service also expressed interest in the idea.

Mobile parcel locker

How it works: In this final scenario, AVs completely automate delivery. An AV would function as a parcel locker on wheels, where each compartment acts as a mailbox, holding the mail for one address. Postal employees would scan packages and mail and load them into the appropriate compartments at the vehicle depot. Customers would request delivery through the Postal Service's mobile app, at which time the AV drives to them on its own. They receive an alert when it arrives, meet the mobile parcel locker outside, unlock their compartment via a keypad or the app, retrieve what is inside, and the vehicle continues on to its next destination.

Alternatively, the mobile parcel locker could have one compartment and an automated sorting system in the interior. Mail and packages could be loaded into the sorter in any order, which would take less time and use space more efficiently. Upon reaching an address, the sorting machine in the interior finds the right items and moves them into the compartment for retrieval.

Type of delivery: When market-ready, the mobile parcel locker will likely be applicable only for specific delivery areas or customer segments. Some customers may not like losing their neighborhood carrier or would find it inconvenient to schedule deliveries or go outside to make the pickups. Nevertheless, this AV model would be the most transformative of all. It would enable on-demand delivery, increase customer convenience, eliminate package theft from porches, reduce failed delivery, and remove the need for receipt-confirmation signatures.

Current testing: Google has filed a patent for an autonomous parcel locker truck while other delivery companies, such as DPD Germany, have envisioned similar solutions.[70] Specialty delivery providers have envisioned similar methods, such as Oxbotica's autonomous grocery delivery vehicle.[71]

68 This is becoming more common as ecommerce grows, especially during the holiday season in November and December. Carriers that cannot fit their entire package load must make a round of deliveries before returning to the post office to pick up the rest.
69 DHL Trend Research, 2014, p. 31.
70 Murphy, 2016 and DPD Group 2016.
71 Brett Williams, "Driverless Vans Will Now Deliver Groceries in London," *Mashable,* June 28, 2017 http://mashable.com/2017/06/28/london-self-driving-grocery-deliveries/#V4UYPmHe4PqF.

Trucking

The Postal Service currently contracts out most of its long-haul transportation through Highway Contract Routes (HCRs). Nevertheless, there are reasons why it is still worthwhile for the Postal Service to investigate autonomous trucking applications:

- Plant-to-plant transportation is an integral part of the network and a high cost center. In FY 2016, the Postal Service spent $3.8 billion on HCR contracts.[72] Additionally, the Postal Service owns 7,600 tractor-trailers and large cargo vans that it uses to transport mail within plant facilities.[73] These owned trucks provide the Postal Service a chance to directly test the technology.
- There is a good chance autonomous trucking will become viable before autonomous delivery due to the less complex driving environment of highways. The return on investment is also more immediate with autonomous trucks because of their greater fuel efficiencies.
- The Postal Service could bring additional plant-to-plant transportation in-house to gain control over the trucking value chain. If it elects to keep the current contract model, it can give preference to contractors who use AVs to increase efficiency. Many contractors may already be looking into AVs, knowing that in the future they will be at a competitive disadvantage without them. For small mom-and-pop trucking companies that cannot afford the upfront investment, the Postal Service could help with the cost in exchange for lower contract fees over time.

Should the Postal Service decide to explore AV applications for long-haul transportation, it could consider low-level automation to enable platooning, or fully autonomous trucking.

Connectivity and Low-Level Automation Enables Platooning

How it works: Truck platooning refers to two or more truck drivers in specially equipped trucks linking up into compact groups on the highway, which saves fuel by reducing wind resistance. To form a platoon, truck drivers put themselves in a line while travelling on the highway, and, at their command, the system draws the trucks closer together, linking the active safety systems. Overseen by the front driver, the Adaptive Cruise Control and safety systems on the front truck control the speed of the platoon, and the platooning system establishes an optimum following distance between the trucks.[74] In the future, advanced platooning systems may provide lane-keeping assist or control steering as well as speed.[75] When fully autonomous trucks emerge, companies may be able to send out platoons with a driver only in the lead truck, much like a train engine pulling freight cars behind it, or even no driver at all.

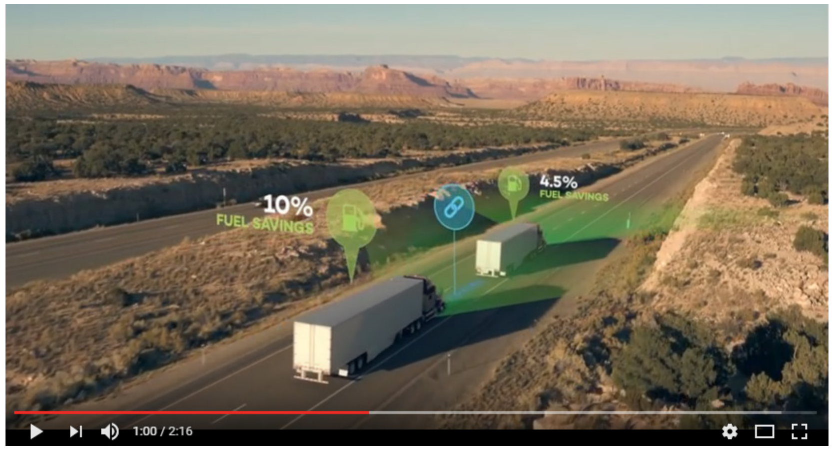
Type of transportation: Platooning requires multiple trucks to follow the same route, so it is best for high density freight corridors. The trucks do not need to be owned by the same company, however. Part of the vision for platooning is enabling it across fleets. For example, the software could alert a Postal Service truck driver and a Walmart truck driver that they are near each other and travelling a similar route, and ask if they want to platoon to mutual benefit. The system would then guide them into position and keep them aligned until either decides to break the platoon. More than two-thirds of long-haul trips in the U.S. are along the same routes, and a 2016 survey found that up to 45 percent of trucks could have formed a platoon during their trip if equipped with the capability.[76]

72 U.S. Postal Service, Cost Segments and Components, 2016, http://about.usps.com/who-we-are/financials/welcome.htm/.
73 To put that in perspective, Walmart owns 6,500 trucks (and 70,000 trailers). U.S. Postal Service Office of Inspector General, *Fuel Consumption and Cost Risk Mitigation*, 2017, p. 6.
74 Some people use the phrase “cooperative adaptive cruise control” to refer to platooning. Cooperative adaptive cruise control refers to systems that control speed only. For the purposes of this paper, we use platooning to discuss systems that control speed only and systems that control speed and steering.
75 There are indications that hands-free highway driving is coming soon and some steering features are already available. American Trucking Associations Technology and Maintenance Council, 2015, p. 9.
76 Ibid., pp. 22-24.

Current testing: Platooning is being tested across the industry. One company offering a platooning solution is Peloton Technology (see Video 1). The vehicles communicate over Dedicated Short Range Communications (DSRC) to coordinate braking, thereby reducing the lag time between when each vehicle begins slowing.[77]

The technology has also been tested on the open road. In 2016, the European Union's European Truck Platooning Challenge saw six platoons, each two to three vehicles in length, successfully navigate both highway and urban environments across five countries. Dense traffic, bad weather, and construction zones proved to be challenges, but ultimately, "everything went smoothly."[78]

Video 1: Peloton Platooning Vision



Source: Peloton Technology.

Fully Autonomous Trucking

How it works: The long-term vision for autonomous trucks does not require a human driver for either the whole trip or portions of it. One concept, called "exit-to-exit," has a person drop the truck off at a staging area near a highway entrance, whereupon it drives autonomously on the highway to another staging area near the destination exit, at which point a different person gets in and brings it through local roads to its final destination.[79] Another concept has the human operator remain in the cab throughout the trip but doing other productive activities or resting, which might not be counted as active drive time for the hours-of-service rules that contribute to an industry-wide driver shortage.

Type of transportation: Fully autonomous trucks can drive in all environments, though they would be used primarily on highways.

Current testing: Driverless trucks are already a reality in some closed environments.[80] Mining company Rio Tinto uses more than 70 autonomous trucks to operate an around-the-clock mining operation in Australia.[81] When it comes to public roads, AV startup Otto made headlines in 2016 by facilitating the world's first commercial shipment — 50,000 cans of Budweiser were carried 120 miles — by self-driving truck monitored by an on-board driver in an exit-to-exit test.[82] Similarly, incumbent companies such as Freightliner have been working on their versions of autonomous trucks.[83]

Video 2: Otto Debuts Fully Autonomous Truck

Source: Uber Advanced Technologies Group.

77 DSRC is a two-way, short - to medium-range wireless communication mechanism. The Federal Communications Commission set aside 75 MHz of spectrum in the 5.9 GHz band for DSRC in vehicle safety systems. U.S. Department of Transportation, "DSRC: The Future of Safer Driving," https://www.its.dot.gov/factsheets/dsrc_factsheet.htm.

78 The five countries were Sweden, Germany, Denmark, Belgium, and the Netherlands. European Truck Platooning, *European Truck Platooning Challenge 2016: Creating Next Generation Mobility,* 2016, https://www.eutruckplatooning.com/Support/Booklet+Lessons+Learnt/default.aspx#folder=529849.

79 Leslie Hook, "Out of Road: Driverless Vehicles and the End of the Trucker," *Financial Times,* March 30, 2017*,* https://www.ft.com/content/2d70469c-140a-11e7-b0c1-37e417ee6c76.

80 Mining represents an excellent use case for AV technology, due to remote locations, hazardous working conditions, and a shortage of skilled labor. Caterpillar, "Customer Solutions: Autonomous Operations," http://www.caterpillar.com/en/company/innovation/customer-solutions/autonomous-operations.html.

81 Dave Gershgorn, "Self-driving, 416-ton Trucks Are Hauling Raw Materials around Australia," *Quartz,* December 29, 2016, https://qz.com/874589/rio-tinto-is-using-self-driving-416-ton-trucks-to-haul-raw-materials-around-australia/.

82 Alex Davies, "Uber's Self-Driving Truck Makes Its First Delivery: 50,000 Beers," *Wired*, October 25, 2016, https://www.wired.com/2016/10/ubers-self-driving-truck-makes-first-delivery-50000-beers/.

83 For more information on Freightliner's autonomous truck "Inspiration," see http://www.freightlinerinspiration.com/.

A Possible Implementation Approach for the Postal Service

Despite the factors still hindering AV availability, it seems clear that this is where the future of transportation is headed. The pace of innovation suggests that we can expect highly-autonomous vehicles to be available within 10 years. In order to be prepared, it will be important for the Postal Service to stay informed and continue to explore the technology, while thinking strategically about how to use AVs to strengthen its position in the delivery market.

Similar to what other logistics companies are doing, the Postal Service could take a gradual approach in order to gain familiarity with the technology and lay the building blocks for its development. This would involve a number of progressing steps:

- The first step would be to equip postal vehicles with low levels of autonomy and connectivity in order to increase safety and collect useful data. The Postal Service has already begun this step by including language about vehicle telematics and safety sensors in its procurement request for a new fleet of delivery vehicles.[84]
- It could then test higher-level AV applications where practical and permitted, as it is doing with its prototype AV for rural delivery. This testing would allow the Postal Service to determine the type of tools and expertise it needs to manage an AV system, create buy-in among employees, and identify the investment that would be required.
- Finally, the Postal Service could start the actual deployment, in a pilot environment, of various levels of AVs based on a feasibility study that considers operational impact, cost, public opinion, legality, and the Postal Service's own long-term transportation strategy.

While this gradual approach would allow the Postal Service to minimize operational and financial risks, USPS already considers its aging fleet to be a hindrance to competitiveness — a disadvantage that only grows as other logistics players start to explore AVs.[85] To stay relevant, it will be important for the Postal Service to leverage its existing strengths within the brand-new delivery models that AVs will create.

For example, in the race to fully automate delivery, one problem lacking an immediate solution is last-meter delivery — the act of getting items from an AV to the customer. Fully autonomous delivery requires the customer to retrieve items from the AV themselves, or the addition of another mechanism that can move items to a front door or mailbox. Drones and robots may play a role, though their efficacy is not proven. They may not be viable solutions when the customer is not at home, is unable to use the digital interface, or simply prefers a traditional delivery mode.

The last-meter problem could open up opportunities for the Postal Service. With its network of carriers, the Postal Service is best-positioned to fill that last-meter gap. Post offices could act as hubs where third-party AVs drop off mail and packages for local delivery. The combination of post offices, carriers (made more efficient by riding in AVs), and digital tools that enable coordination with third-parties could create a new role for the Postal Service in the last-mile delivery models of the future.

84 The request for proposal includes safety features such as bumper sensors and back-up cameras as well as vehicle telematics, which are listed as an optional yet desirable feature.
85 U.S. Postal Service, "2016 Report on Form 10-K," https://about.usps.com/who-we-are/financials/10k-reports/fy2016.pdf, p. 10.

Conclusion

Automakers and technology companies are rapidly building prototypes and testing autonomous vehicles. It will still be years before fully self-driving vehicles are available to customers, but lower-level automated features such as park assist and lane departure warning are common today.

The Postal Service is already researching how it could leverage AV technologies to facilitate rural delivery, and plans to conduct testing in the future. To complement their effort, the OIG studied the market and conducted interviews to identify further applications of AVs in logistics, both in the delivery sphere and in trucking. These applications could increase the safety and convenience of carriers and drivers, save fuel, increase productivity, and promote the Postal Service as an innovative brand.

To achieve these benefits while limiting the operational and financial risks, we suggest the Postal Service takes a step-by-step approach that involves testing the technology first, gradually automating its vehicles and operations where it makes strategic sense, and refining the strategy as the technology, market, and regulatory framework evolve. Given that the Postal Service is embarking on a multi-year replacement of its vehicle fleet, now is an opportune time to consider what autonomous vehicles have to offer and to lay the building blocks for their potential future deployment.

Appendices

Click on the appendix title to the right to navigate to the section content

Appendix A: Autonomous Vehicle Technology in Detail

Levels of Automation

Autonomous vehicles and driverless cars are not, strictly speaking, synonymous terms. Rather, "autonomous" refers to a continuum of vehicle intelligence that includes everything from cruise control and park assist, which are semi-autonomous features common in cars today, to truly driverless vehicles, which are still many years in the future. The industry standard for talking about this continuum is the levels defined by SAE International and displayed in Table 3.

Table 3: SAE International Levels of Automation

Level	Definition	Timeline to Market Availability
Level 0 — No Automation	The full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems.	Widely available now. Cars with no autonomy have been available for over 100 years.
Level 1 — Driver Assistance	The driving mode-specific execution by a driver assistance system of *either* steering *or* acceleration/deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task.	Widely available now. Features such as park assist or adaptive cruise control are available as options on many new cars.
Level 2 — Partial Automation	The driving mode-specific execution by one *or more* driver assistance systems of *both* steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task.	Available now, particularly as upgrades. The Honda Sensing system and Audi's Traffic Jam assist are examples.
Level 3 — Conditional Automation	The driving mode-specific performance by an Automated Driving System of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene.	Beginning to be available now. Tesla's Autopilot is already available. Other carmakers plan to offer Level 3 vehicles by 2020, while others plan to skip this level.
Level 4 — High Automation	The driving-mode specific performance by an Automated Driving System of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene.	Not yet available. Earliest goals set by carmakers are in 3-5 years, although 10 years may be more likely.
Level 5 — Full Automation	The full-time performance by an Automated Driving System of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver.	Not yet available, and some would argue not even achievable. At least 10 years away.

Source: SAE International J3016, OIG Analysis.

Executive Summary

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Autonomous vehicles require the combination of multiple technologies to function properly. Level 4 and 5 AVs especially need cutting-edge hardware and software because they are expected to drive with no human intervention, and do so more safely and efficiently than a person. This appendix details four of the most important types of technology found in AVs: sensors, 3D maps, connectivity, and artificial intelligence.

Sensors: Enabling the Vehicle to See

Autonomous vehicles primarily use three types of sensors to "see" the world around them: cameras, lidar, and radar.

Cameras

Cameras are the foundational piece of an autonomous vehicle's sensing array. They are the most mature type of sensor, which makes them inexpensive, but they also generate the most sophisticated imagery.

AV video cameras, like human eyes, capture a two-dimensional image of the world and use contextual clues to interpret it as a three-dimensional environment, although they are not as good at that as lidar. Their level of detail is superior to other vision sensors; they can read street signs, lane markers, human faces, and colors, among other things. They are not yet sophisticated enough, however, to determine the difference between a police officer signaling a car to stop and a carjacker signaling a car to stop.

They can also pick up emitted light, like the brake light of the car in front of you, which lidar and radar cannot.[86] Like the human eye, their vision is limited by the amount of available light. Cameras have trouble seeing in the dark and they can be confused by shadows cast on or by objects.

Cameras cost less than $200 — far cheaper than lidar.[87] They are already present in most vehicles that feature advanced driver assistance systems (ADAS) such as backup-assist, collision avoidance, or lane-keep assist. In those vehicles, they are built in to the body, but a vehicle can be easily retrofitted with a front-facing camera behind the rear-view mirror. Cameras on all sides of the vehicle would provide a 360-degree view necessary for autonomous driving.

Lidar

An acronym for "light detection and ranging," lidar works through a principle similar to radar. Instead of sending out radio waves and measuring how long it takes them to bounce off an object and come back, lidar sends out pulses of light. The pulses travel until they hit a surface and ricochet back to the sensor, which reveals how far away the surface is. By sending out millions of pulses per second in every direction, a lidar unit receives millions of data points, collectively called a point cloud, that it uses to create a 3D map of its surroundings.[88]

Current top of the line lidar units have a range of 120 meters, although developers want to push that number past 200.[89] Unlike a camera, it sees equally well in the dark. At the same time, it can only detect the shape of objects, not their color or subtle details.[90] So, while it can identify a stop sign by its shape, it doesn't know that the sign is red or that it has a word on it. To date, road tests have mostly occurred in near-perfect weather conditions and lidar's ability to "see" properly in heavy fog or preciptiation remains a problem.[91] Additionally, it uses a lot of computing power to process its point cloud.[92]

86 Brad Templeton, "Cameras or Lasers?," http://www.templetons.com/brad/robocars/cameras-lasers.html.
87 Boston Consulting Group, *Revolution in the Driver's Seat: The Road to Autonomous Vehicles*, April 21, 2015, https://www.bcgperspectives.com/content/articles/automotive-consumer-insight-revolution-drivers-seat-road-autonomous-vehicles/?chapter=4.
88 Aakash Goel, "What Tech Will it Take to Put Self-Driving Cars on the Road?," Engineering.com, http://www.engineering.com/DesignerEdge/DesignerEdgeArticles/ArticleID/13270/What-Tech-Will-it-Take-to-Put-Self-Driving-Cars-on-the-Road.aspx.
89 John R. Quain, "What Self-Driving Cars See," *The New York Times*, May 25, 2017, https://www.nytimes.com/2017/05/25/automobiles/wheels/lidar-self-driving-cars.html?_r=0.
90 Devin Coldewey, "WTF is lidar?," *TechCrunch*, February 12, 2017, https://techcrunch.com/2017/02/12/wtf-is-lidar/.
91 Wang, 2017, and Coldewey, 2017.
92 Davide Santo, "Autonomous Cars' Pick: Camera, Radar, or Lidar," *EE Times*, July 7, 2016, http://www.eetimes.com/author.asp?section_id=36&doc_id=1330069.

Traditional lidar units for autonomous vehicles consist of a small cylinder mounted to the roof. Inside are 16-64 lasers, lined up vertically. The lasers spin in a circle up to 20 times per second, firing off pulses of light.[93] This is the most practical way to deploy lidar because of its unfettered 360 degree view on the roof, but it's not terribly attractive. Automakers are working to design AVs where the lidar sensors would be built into the front and rear bumper to make them less obtrusive. Corner units would have a much smaller range of visibility, however, so a vehicle would need at least four instead of one.

The price of lidar sensors has come down substantially in recent years but still runs in the thousands of dollars. Installing four of them in a vehicle is prohibitively expensive. If the price falls into the hundreds of dollars, though, it suddenly becomes feasible.[94]

Radar

While cameras are prerequisites for AVs and lidar is a clear second choice, radar is considered more of an auxiliary sensor. Radar works by sending out radio waves and measuring the time they take to deflect off objects and back to the sensor, like lidar does with light pulses. Its big advantage is that it can precisely detect the speed and direction of moving objects using the Doppler effect, which is the change in frequency or wavelength of a wave based on the movement of the object it deflected off of.[95]

Radar helps an AV understand what the vehicles around it are doing. If the car in front is slowing down, the AV knows to start slowing down as well. It can even detect moving objects that are not within a direct line of sight by bouncing off or under other objects and hitting the hidden one.[96] Radar is already used in ADAS systems for short-range (20 meters) applications like blind-spot detection and long-range (200 meters) applications like adaptive cruise control.[97]

Radar sensors are inexpensive and use little computation power.[98] However, they do not produce a comprehensive picture of the surrounding environment and are therefore best used to add redundancy into the system.

3D Maps: Positioning the Vehicle in the Wider World

No matter how good an AV's sensors are, they may not be enough to guarantee the vehicle's safe navigation on their own. It is preferable to check their information against existing images of the road to ensure its accuracy — a process called mediated perception because of the way two sources of data are mediated with each other.[99] There are three primary reasons for this extra layer of redundancy: precise localization of the vehicle on the road, efficiency of computing power, and safety.

3D Maps Offer Precise Localization

Many of today's cars have built-in navigation systems that combine GPS with digital maps to show drivers where they are and which direction they should be driving. GPS is built into AVs as well, but it is not nearly accurate enough to localize a vehicle precisely — as anyone who has had GPS tell them they are standing in the middle of a river knows. It is only accurate to within 8 meters, and only where it receives a satellite signal. Some places — inside tunnels or near tall buildings, for instance — have weak or blocked signals.[100] Human drivers adjust effortlessly to a discrepancy of a few meters; AVs do not. They need to know exactly where they are on the road, to within about four inches.[101]

93 Wang, 2017.
94 Ibid.
95 Northwestern University Qualitative Reasoning Group, "What is the Doppler effect?," http://www.qrg.northwestern.edu/projects/vss/docs/communications/3-what-is-the-doppler-effect.html.
96 Robert Ferris, "Tesla Autopilot appears to 'predict' accident in front of it," *CNBC*, December 28, 2016, http://www.cnbc.com/2016/12/28/tesla-autopilot-appears-to-predict-accident-in-front-of-it.html.
97 "Radar Sensing for Driverless Vehicles," *Digikey*, November 2, 2016, https://www.digikey.com/en/articles/techzone/2016/nov/radar-sensing-for-driverless-vehicles.
98 Ali Osman Ors, "RADAR, camera, and LiDAR for autonomous cars," *NXP*, May 24, 2017, https://blog.nxp.com/automotive/radar-camera-and-lidar-for-autonomous-cars.
99 Christopher Brewer, "Building Ford's Next-Generation Autonomous Development Vehicle," *Medium*, December 27, 2016, https://medium.com/@ford/building-fords-next-generation-autonomous-development-vehicle-82a6160a7965.
100 McKinsey & Company, "Self-driving car technology: When will the robots hit the road?," May 2017, http://www.mckinsey.com/industries/automotive-and-assembly/our-insights/self-driving-car-technology-when-will-the-robots-hit-the-road?cid=other-eml-alt-mip-mck-oth-1705&hlkid=8918aaf6e62342b881930ff9546883db&hctky=929-5237&hdpid=cba97ba2-ba30-41c0-b01e-6121103a8fe7.
101 Neal E. Boudette, "Building a Road Map for the Self-Driving Car," *The New York Times*, March 2, 2017, https://www.nytimes.com/2017/03/02/automobiles/wheels/self-driving-cars-gps-maps.html.

3D maps of the streetscape provide that precision. They are created the same way Google created its street maps — by mounting a 360-degree camera on a car and driving it down roads one by one. In this case, a high-definition camera or a lidar sensor can be used. Engineers pore over the images and manually label important objects: traffic lights, stop signs, lane lines, etc.[102] (Some companies are working on algorithms that will handle this time-consuming job automatically.) The result is a three-dimensional, high-definition, 360-degree map of the street that is uploaded into an AV's hard drive. The more roads mapped in advance, and continually mapped as conditions change, the more an AV's potential territory expands.

As the AV moves, GPS tells it where it is to within a few meters. The computer compares its existing map images to the real-time images being generated by its sensors. Comparing the proximity and angle of nearby objects to the proximity and angle of the same objects on the map tells the vehicle exactly where it is standing.[103]

3D Maps Improve the Efficiency of Computing Power

Digital maps also ease the burden on an AV's processor. Just as humans are more relaxed while driving around their own neighborhood than a new one, AVs like to know what is around each turn. An AV making all its decisions based on real-time sensor data would have to notice everything and decide whether it is important — a computing-intensive task. A 3D map gives it advance warning of what is ahead; it can therefore focus its attention primarily on the new objects that were not on its map, like cars and pedestrians.[104]

3D Maps Increase Safety for Vehicles and Passengers

Finally, 3D maps make for a safer drive. Sensors do not recognize objects with 100 percent accuracy. Bad light, bad weather, or obstructed views can affect them. But if the vehicle already knows what should and should not be coming up, it does not need to rely solely on sensor inputs to decide how to proceed. Also, if a sign is blocked or lane lines are covered by snow, sensors cannot find them, but the map still knows they are there. Essentially, maps provide another layer of redundancy, just like radar is a layer of redundancy for cameras.

Connectivity: Vehicles Communicating with Everything

Establishing wireless connections between an AV and other entities, known as vehicle-to-everything (V2X) connectivity, is not a requirement for autonomous driving but can be useful. V2X includes vehicle-to-vehicle, vehicle-to-infrastructure, and cloud connectivity.

- **Vehicle-to-vehicle (V2V) communication:** allows vehicles to share information with each other. Human drivers communicate with each other by, for example, using turn signals. V2V is a greatly amplified version of that. Such transmissions could include information about the vehicles themselves, such as their speed, direction, or intentions to stop or turn.[105] A car that is braking hard would broadcast that information to the car behind it, allowing the rear car to start braking and avoid a collision. Understanding what other vehicles are doing helps an AV make decisions without having to rely on its sensors, which would be especially useful when AVs have to share the road with unpredictable human drivers. Vehicles could also use V2V communication to send information about the driving environment. Knowing about blocked lanes, accidents ahead, and icy roads would allow AVs to reroute or adjust their driving behavior.

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102 Bradley Berman, "Whoever Owns the Maps Owns the Future of Self-Driving Cars," *Popular Mechanics*, July 1, 2016, http://www.popularmechanics.com/cars/a21609/here-maps-future-of-self-driving-cars/.
103 Greg Miller, "Autonomous Cars Will Require a Totally New Kind of Map," *Wired*, December 15, 2014, https://www.wired.com/2014/12/nokia-here-autonomous-car-maps/.
104 Boudette, 2017.
105 U.S. Department of Transportation, *NHTSA Issues Notice of Proposed Rulemaking and Research Report on Vehicle-To-Vehicle Communications*, 49 CFR Part 571, Docket No. NHTSA-2016-0126.

- **Vehicle-to-infrastructure (V2I) connectivity:** allows vehicles to receive similar updates about road conditions, but on a larger scale. Say an accident at an intersection had blocked all cars from passing through and caused traffic to back up. A sensor on the traffic light could register this circumstance and broadcast it to all vehicles in the vicinity, telling them to stay away. Infrastructure sensors could even regulate the normal flow of traffic by controlling the speed or following distance of all AVs on a stretch of road.[106] Data can flow the other direction as well. Today, many cities use the Opticom system on some of their traffic lights; emergency vehicles approaching an intersection send a signal that turns the light green for them and red for everybody else.[107] Civilian AVs could theoretically do the same thing to connected traffic lights; if an intersection was otherwise empty, an approaching AV could tell the light to turn green to allow it to pass through without stopping.

- **Cloud connectivity:** allows vehicles to send and receive data from a faraway source.[108] Most commonly, this would mean receiving software updates from the companies that contribute to the AV's artificial intelligence, the same way our mobile phones get their apps updated automatically. AVs would receive regular software updates to add features, improve antivirus and intrusion protection, and refine driving habits based on the machine learning done by other AVs around the world. Although updates could be uploaded into AVs manually rather than through a wireless connection, this is no more practical than updating one's home computer with a flash drive every few days.

Connectivity Improves Safety but is not Without Challenges

The DOT believes strongly in connectivity as a safety measure and a prerequisite for autonomy. In December, it issued a Notice of Proposed Rulemaking that would mandate the inclusion of V2V capability in all new light-duty vehicles, whether automated or not.[109] If adopted by every light-duty vehicle in the country, it said, V2V could prevent 400,000-600,000 crashes and save 780 to 1,080 lives each year.[110] The proposed rule would establish a standardized messaging format for all V2V communication, which would be transmitted using Dedicated Short Range Communications (DSRC) technology. A month after the V2V proposal, the DOT's National Highway Administration released guidance on V2I technology with the intent to encourage transportation network participants to start planning for adoption.[111]

The introduction of wireless connectivity to vehicles brings with it a bevy of new challenges. First and foremost is cyber security. An AV that is connected to the outside world — essentially a computer on wheels — can theoretically be hacked, with potentially life-threatening consequences.[112] There are privacy concerns as well. By constantly broadcasting data about its movements, a connected vehicle is leaving a trail of breadcrumbs that could be used by anyone with access to the data, in much the same way our internet searches are used to advertise to us. There is also the challenge of limited bandwidth. The more messages sent and received over a wireless network, the slower they get. Engineers will have to ensure that the most vital data packets always reach AVs quickly enough for them to make driving decisions.[113]

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106 Vicente Milanes, Jorge Villagra, Jorge Godoy, Javier Simo, Joshue Perez Rastelli, et al.,"An Intelligent V2I-Based Traffic Management System," *IEEE Transactions on Intelligent Transportation Systems*, IEEE, 2012, 13 (1), pp.49-58, https://hal.inria.fr/file/index/docid/732884/filename/An_Intelligent_V2I-Based_Trafi_c_Management_System.pdf, p. 49.
107 "GTT to Highlight Traffic Priority Control for Emergency Vehicles at EMS2017 Copenhagen," *Journal of Emergency Medical Services*, http://www.jems.com/articles/news/2017/05/gtt-to-highlight-traffic-priority-control-for-emergency-vehicles-at-ems2017-copenhagen.html.
108 Eric A. Taub, "Your Car's New Software Is Ready. Update Now?" *The New York Times*, September 8, 2016, https://www.nytimes.com/2016/09/09/automobiles/your-cars-new-software-is-ready-update-now.html.
109 U.S. Department of Transportation, *Notice of Proposed Rulemaking: Federal Motor Vehicle Safety Standards; V2V Communications*, 49 CFR Part 571, Docket No. NHTSA-2016-0126, https://www.federalregister.gov/documents/2017/01/12/2016-31059/federal-motor-vehicle-safety-standards-v2v-communications.
110 U.S. Department of Transportation, *Vehicle-to-Vehicle Communication Technology*, https://www.safercar.gov/staticfiles/safercar/v2v/V2V_Fact_Sheet_101414_v2a.pdf.
111 U.S. Department of Transportation, "FHWA Announces Vehicle-to-Infrastructure Guidance," January 19, 2017, https://www.fhwa.dot.gov/pressroom/fhwa1703.cfm.
112 Andy Greenberg, "Hackers Remotely Kill a Jeep on the Highway—With Me in it," *Wired*, July 21, 2015, https://www.wired.com/2015/07/hackers-remotely-kill-jeep-highway/.
113 Chuck Tannert, "Self-Driving Cars: A Crash Course In Communication," *Fast Company*, January 8, 2014, https://www.fastcompany.com/3024360/driverless-cars-a-crash-course-in-communication.

Figure 4: Promoting an Efficient Transportation System with Vehicle-to-Vehicle Connectivity

Source: U.S. Department of Transportation.

Artificial Intelligence: Interpreting High Volumes of Data

The computer brain of an autonomous vehicle takes in data from its sensors and V2X connections, interprets it, mixes it with any pre-programmed data from a 3D map or other source, and makes decisions about how to behave based on the result. It does this countless times every minute. The decisions it makes are based on its artificial intelligence. Although sensors also contain some AI, this section refers only to the AI in a vehicle's central computer. There are two basic ways to create artificial intelligence in AVs: algorithmic rules and deep learning.

Algorithms are More Traditional but too Rigid

A rules-based approach is more traditional. Engineers program the computer with millions of lines of code that tell it what to do in every scenario it might encounter. (Swerve left if a deer runs across the road but there is another car on the right, slow down for a Yield sign ahead, stay inside of the dashed white lines, etc.) Writing code for every possible decision is a time-consuming and imperfect task, however.[114] An ambiguous piece of sensor data or a new situation could confuse the AV.

Deep Learning Teaches Vehicles to Think

Deep learning is more controversial but offers more potential benefits. With this method, the AV is not told what to think, but rather how to think. Its neural network is then "trained" on proper driving technique by feeding into it a huge amount of data that was

114 Robert Toews, "The AI Debate Critical To The Future Of Autonomous Vehicles," *Forbes*, March 9, 2017, https://www.forbes.com/sites/currentaccounts/2017/03/09/the-ai-debate-critical-to-the-future-of-autonomous-vehicles/#6b04ba857179.

captured during real-life human drives.[115] The data is generated by a human driving around in a vehicle equipped with sensors that record both the world outside of the vehicle as well as the driver's actions inside of it (turning the wheel, tapping the brakes, turning on the blinker, and so on). Those two data records are uploaded into the neural network, which studies what external factors caused the driver to take each action. It then emulates those actions on its own.

Figure 5: A Vehicle Learning What to Focus On

Source: NVIDIA.

Figure 5 is a visualization of what PilotNet, a deep learning vehicle created by tech company NVIDIA, has chosen to focus on when it drives.[116] The green highlights reveal that it is most aware of lane markers, other cars, and the edges of its driving space — the same things a human driver would be most aware of. PilotNet was never coded to do that; it made the decision on its own through observation.

Deep learning is considered more comprehensive than rules-based programming because it includes real-world actions and reactions. While a rules-based AI needs to be told in code what a pedestrian looks like, for example, a deep learning AI can decide for itself by observing that: human drivers always yield to certain moving blobs, pixelated images of those moving blobs all share certain characteristics, so therefore all blobs with those characteristics are pedestrians.[117]

The drawback of deep learning is that it does not reveal why the neural network reaches the conclusions it does.[118] If an AV with deep learning software fails to stop at a red light, there is no way to understand why it did not see or register the light as a signal to stop. Many designers feel uncomfortable not being able to reprogram this kind of black box.

115 Ibid.
116 Danny Shapiro, "Reading an AI Car's Mind: How NVIDIA's Neural Net Makes Decisions," April 27, 2017, https://blogs.nvidia.com/blog/2017/04/27/how-nvidias-neural-net-makes-decisions/.
117 Mark Harris, "New Pedestrian Detector from Google Could Make Self-Driving Cars Cheaper," *IEEE Spectrum*, May 28, 2015, http://spectrum.ieee.org/cars-that-think/transportation/self-driving/new-pedestrian-detector-from-google-could-make-selfdriving-cars-cheaper.
118 Toews, 2017.

Appendix B: Current Postal Service Research

The Postal Service has already considered using automated vehicle technology in its delivery operations.[119] It conducted a use case analysis in 2014 and, based on the results, decided that rural delivery routes were an appropriate place to introduce some early AV technology. Rural roads are less congested, have fewer sensory inputs, and are therefore more forgiving of an imperfect AV model.

The Postal Service is partnering with the University of Michigan on a prototype Autonomous Rural Delivery Vehicle (ARDV). The university is a major player in the fast-growing AV field, buoyed by its proximity to Detroit's auto manufacturers. Under the agreement, the university is engineering the prototype from scratch based on postal specifications. Michigan would own the intellectual property and lease the finished product to the Postal Service.

The right-hand-drive ARDV would be used in a manner similar to that described in the "shuttling the letter carrier around" use case described in the paper. The carrier would sit behind the wheel, sort mail on the move, and deliver through the window while the vehicle handles the driving. The prototype only uses Level 3 technology, however, meaning the driver has to be ready to assume control at all times.

Three types of sensors enable the automation: cameras on the front and back, a 360-degree lidar "egg" on the roof, and a flash lidar sensor in the rear. Magnetic sensors in the wheels count the number of revolutions and note the degree of tire traction, which helps inform the vehicle's artificial intelligence. Initially, the ARDV will need to be "trained" on a delivery route; someone will drive the route manually while the AI learns where it is supposed to go. From then on, it can follow the pre-determined path while using its sensors to make small adjustments to avoid obstacles. ARDV project leaders do not anticipate that early versions will be able to drive from the post office to the beginning point of a route, or that they will be able to cross intersections autonomously; those portions of the trip must be handled manually.

There is debate in the AV industry about whether Level 3 automation is safe enough. Many people argue that humans will inevitably let their attention drift if the car is doing a good job driving itself. If an emergency situation arises, requiring the driver to snap to attention, assess the situation, and react appropriately in a split second, it will be very difficult to do so.[120] This is less of a concern for postal vehicles because of their relatively slow speeds and the fact that drivers will be keeping busy with the mail rather than playing on their mobile phone or dozing off. Nonetheless, the Postal Service should consider the risks.

Phase 1 of the ARDV project consists of building the prototype and outlining the human/machine touchpoints that need to be accommodated. For example, after making a delivery, how would the carrier signal the vehicle to move? The mechanism cannot be complicated but it must also be accident-proof — accelerating while the carrier's arm is still in the mailbox would potentially hurt the carrier. Following delivery of the prototype by Michigan in December 2017, the plan is to bring in union representatives to discuss some of the human/machine interaction issues and craft employee training guidelines.

Phase 2 of the project consists of finding a company to manufacture the ARDVs, as well as piloting them on 10 rural routes in 2019. Phase 3 is to deploy the ARDV on 28,000 rural routes around the country by 2022-2025.

The Postal Service is about to begin a wholesale replacement of its old fleet of Long Life Vehicles (LLVs), the ubiquitous white postal trucks, with newer, but still non-automated, models. The Next Generation Delivery Vehicles (NGDVs) will be rolled out over

119 Dinh, 2017.
120 McKinsey & Company, *Self-driving car technology: When will the robots hit the road?*, May 2017, http://www.mckinsey.com/industries/automotive-and-assembly/our-insights/self-driving-car-technology-when-will-the-robots-hit-the-road?cid=other-eml-alt-mip-mck-oth-1705&hlkid=8918aaf6e62342b881930ff9546883db&hctky=929-5237&hdpid=cba97ba2-ba30-41c0-b01e-6121103a8fe7.

the course of seven years, beginning in 2019. Under the terms of its procurement contracts with manufacturers, the Postal Service will be able to mandate the addition of autonomous components at any time, with one year's notice. Therefore, if its ARDV pilots prove successful, or if it decides to embrace other AV technology, it can change course within the context of its existing purchase contract.

One interesting idea floated by the Postal Service's vehicle engineers is to affix barcodes to mailbox poles on rural routes. They would be immediately identifiable by the ARDV's cameras, allowing the vehicle to stop at precisely the right spot in front of the mailbox, as well as alerting the carrier to any packages going to that address. This is an example of technology that could be added to new vehicles over the course of the procurement contract. The Postal Service eventually plans to explore city delivery, having one vehicle serve two carriers, and eventually removing the steering wheel and pedals altogether.

Appendix C: Swiss Post and Autonomous Vehicle Technology Case Study

Swiss Post is often a leader among postal operators when it comes to testing new technology.[121] It had particular interest in testing autonomous vehicle technology because of its applicability to two distinct services that Swiss Post offers: delivery and a public bus system. Swiss Post CEO Susanne Ruoff, a former manager at IBM, asked her innovation department to look into the technology. Just a year later, in June 2016, Swiss Post debuted two autonomous shuttle buses in the small southern city of Sion.

These AV buses, although they offer rides, are not meant to replicate PostBus service. They are instead a very public pilot of the technology, to see how well it functions in an urban environment. Swiss Post believes that AVs will inevitably introduce deep changes to its business model; the Sion project is preparation for that eventuality. Along with partners Navya, the shuttles' French manufacturer, BestMile, a San Francisco-based AV cloud provider, and École polytechnique fédérale de Lausanne (EPFL), a Swiss university, Swiss Post is carefully monitoring the technology's performance and the public's reaction to it.

Figure 6: Swiss Post Autonomous Shuttle Pilot Vehicle

Source: Swiss Post.

The shuttles, which cost $200,000 apiece, travel in a 1-mile loop through the city center, picking up and dropping off passengers. They are capable of reaching 12 mph but in reality go much slower because of the density of the setting. They have to contend with pedestrians and plenty of cars. Thus far, they have functioned well in predictable situations but have required driver intervention when confronted with an unexpected obstacle like a double-parked car. At one point their sensors were getting confused by falling snow; they thought the snowflakes were solid objects and kept hitting the brakes. Navya has since updated the software.

Drivers are legally required to be present in every shuttle. In addition to periodically taking manual control, they are in charge of explaining the technology to curious passengers. Each received specialized training in the shuttle's driving mechanisms — steering is done via a control pad like that of an Xbox — and in situational planning. Between training and salaries, Swiss Post says personnel-affiliated costs have outrun the cost of the shuttles.

Support for the project has been strong before and since its unveiling. Sion city officials "opened their streets like a playground" while the nation's transportation minister helped fast-track the technical inspections (one sticking point was that all street-legal vehicles had to have a steering wheel). On the customer side, feedback has been positive. Swiss Post announced the initiative well in advance in order to build anticipation, and, sure enough, people have traveled to Sion just to see the buses in action. By May 2017, they had carried 23,000 passengers. People seem willing to trust the technology with their safety — sometimes too willing. Pedestrians will occasionally jump in front of a moving shuttle to see if it stops, which, so far, it always has.

Separately, the delivery division of Swiss Post is looking into AVs as well. Although the PostBus employees have shared their notes from Sion, the two initiatives are run by separate teams. There remains the possibility for collaboration in future, including the adaptation of a shuttle into a mobile parcel locker. For now, the PostBus division is content to focus on the Sion pilot. The buzz it created by being the first European company to offer AV bus service has, officials feel, already done wonders for Swiss Post's brand.

121 Mueggler, 2017 and Golliard, 2017.

Appendix D: List of Interviews

COMPANY/ORGANIZATION	NAME OF CONTACT	DATE OF INTERVIEW
Best Mile	Leemor Chandally, Director of Strategic Partnerships for North America	February 15, 2017
Bishop Consulting	Richard Bishop, Owner of Bishop Consulting	March 27, 2017
Daimler	Stephen Kasih, Head of Last Mile Logistics — Future Transportation Systems	January 6, 2017
DHL	Denis Niezgoda, Robotics Accelerator Lead	May 22, 2017
Duke University Human and Autonomy Lab	Victoria Nneji, Ph.D Candidate in Mechanical Engineering-Robotics	February 21, 2017
Geopost	Olaf Klargaard, Director of Innovation	April 18, 2017
Hyundai Ventures	John Suh, Vice President	March 30, 2017
Intel	Mark Valcich, U.S. Federal Civilian Director, and Sylvia Karmanoff, Industry Solutions Group for Global Transportation	April 4, 2017
Mobileye	Uri Tamir, Director of Strategic Initiatives	March 20, 2017
National Association of Letter Carriers	Jim Holland, Research Director	April 19, 2017
Northrop Grumman	Chuck Chamberlain, Account Manager	March 8,2017
NVIDIA	Tim Wong, Technical Marketing for Automotive, and Fazel Adabi, Public Relations Manager for Automotive	May 18, 2017
OIG	Anthony Spriggs, Professional Development Analyst	June 16, 2017
Peloton Technology	Stephen Boyd, Co-founder and Vice President of External Affairs, and Jonny Morris, External Affairs and Public Policy Lead; subsequent input also provided by Geoff Johnson and Nandi Chhabra of Peloton External Affairs	March 24, 2017
Swiss Post — Innovation	Thierry Golliard, Head of Open Innovation and Venturing	March 30, 2017
Swiss Post — Post Auto	Martina Mueggler, Leader Innovations and Product Management	February 28, 2017
Toyota Research Institute	Jane Lappin, Director of Government Affairs and Public Policy	March 17, 2017
U.S. Postal Service	Han Dinh, Program Director for Vehicle Engineering, Don Crone, Manager of Technology Acquisition and Program Management, and Joseph Seiss, Program Manager for Vehicle Engineering	March 22, 2017
UPS	Keith Kellison, Senior Vice President of Global Public Affairs, and Jim Bruce, Senior Vice President for Global Public Affairs	April 6, 2017
Velodyne	Harris Wang, Strategic Markets Director	March 10, 2017
Volvo Group	Aravind Kailas, Principal Technology Planner	April 11, 2017
Walmart	Tracy Rosser, Senior Vice President for Transportation and Supply Chain	April 12, 2017

Appendix E: Management's Comments

Kevin L. McAdams
Vice President, Delivery Operations

UNITED STATES POSTAL SERVICE

September 28, 2017

CHRISTOPHER BACKLEY
ACTING DIRECTOR, RARC CENTRAL
RISK ANALYSIS CENTER

SUBJECT: Autonomous Vehicles for the Postal Service
RARC-WP-XX-XXX

Postal Service Headquarters appreciates the opportunity to review and comment on the research and information outlined by the Office of Inspector General (OIG) in its Autonomous Vehicles for the Postal Service report. We appreciate the time, effort and resources that the OIG expended in preparing this report.

We see possibilities from each of the seven use cases and the trucking applications outlined that will increase customer satisfaction and cut costs. We are in agreement of opportunities autonomous vehicles present and have began considering changes with our logistics. The Postal Service is one of the most trusted government agencies and desires to maintain public trust. Safety, for our employees and customers, productivity enhancements and fuel cost savings remains paramount.

Our Fleet Management group will continue to explore technical innovations and possibilities to incorporate this investment with future vehicle acquisitions.

for Kevin L. McAdams

cc: CARM
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We conducted work for this white paper in accordance with the Council of the Inspectors General on Integrity and Efficiency's Quality Standards for Inspection and Evaluation (January 2012).