RARC Report

Autonomous Mobile Robots and the Postal Service

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Executive Summary

Autonomous mobile robots (AMRs) use sensors and navigation technologies to transport goods around an open space without a human controlling them. Different forms of autonomous robots have been used in postal sorting centers for years, to move containers and pallets between sorting machines.

Recent leaps in automation technology have expanded the range and complexity of tasks that robots can perform, making them increasingly suitable for real-world use. Companies like Postmates and Yelp's Eat24 have been testing robot delivery of food and convenience items in select cities. Drawn by the potential to reduce labor costs and enable new delivery business models, posts in Germany, Estonia, Switzerland, Portugal, and Australia have been testing latest generation robots both in postal facilities and on the streets.

To better understand the technology's development and identify potential use cases for the Postal Service, the Office of Inspector General (OIG) interviewed robot manufacturers, posts, delivery companies, academics, and other postal stakeholders. Our interviews and research identified a variety of possible applications both in sorting facilities and last mile delivery.

AMRs for Postal Sorting Facilities

For the past three decades, the Postal Service has intermittently tested different versions of AMRs to move mail within facilities, demonstrating the ability of these technologies to replace manual vehicles and save on work hours. In 2018, it plans to deploy AMRs in 25 sorting centers. As these efforts expand, the Postal Service could also consider testing not only heavy-duty AMRs such as autonomous forklifts and tuggers but also newer, smaller AMRs that are more nimble and sophisticated. Doing so could help:

- expand automation beyond transporting mail from one machine to another to include more complex tasks such as hitching containers to AMRs, putting packages and mail trays on sorting machines, and loading and unloading trucks;

Highlights

Autonomous mobile robots (AMRs) use sensors and navigation technologies to move around their environment without human intervention. They can potentially help the Postal Service cut costs, increase efficiency, and enable new services.

The Postal Service has tested different AMRs in its sorting centers in the past and plans to pilot more in 25 facilities in 2018.

A new generation of smaller and nimbler robots automating the movement of mail in plants could further help the Postal Service save on work hours, speed up processing, and use space more efficiently.

Compared to AMRs in plants, most robot delivery applications are still too economically and technologically immature to be scalable in the short term.

Nonetheless, it would benefit the Postal Service to pilot AMRs in delivery, especially using them to assist carriers.

- increase the number of sorting centers that can currently accommodate AMRs, since smaller AMRs do not require as much aisle clearance as large autonomous tuggers, forklifts, and pallet jacks; and

- speed up the rate of processing, by moving smaller batches of mail and packages more frequently with minimal human work effort. This offers the opportunity to process higher volumes without requiring additional space.

In the long run, maximizing the efficiency of these latest generation AMRs requires a well-crafted concept of operations that is more AMR-centric. This includes aligning the other components of the value chain, especially transportation, to the faster pace of sorting operations, and adapting sorting center layouts to best accommodate AMRs.

AMRs for Last-Mile Delivery

To date, the Postal Service has not run any delivery by robot pilots, but it has been tracking the development of the technology. Use cases the Postal Service may want to consider for a pilot of AMRs in delivery include:

- accompanied delivery, where robots transporting mail and packages would follow carriers to help them complete their job faster with less physical effort; and

- independent delivery, where robots would deliver packages to recipients directly and on their own, without a carrier traveling with them.

Compared to AMRs in plants, the use of robots in delivery is too economically and technologically immature to be scalable in the short term, especially for independent robot delivery applications. However, it will be worth continuing to monitor delivery AMRs' technical, economic, and regulatory progress, as well as start testing AMRs for accompanied delivery, which could be implemented earlier and with less operational disruption than independent delivery robots.

Finally, while piloting and experimenting with AMR technologies, both in sorting centers and in delivery, the Postal Service should consider how robots could eventually change the postal network in the future, beyond their ability to reduce work hours.

Observations

Introduction

It will be years before a commuter can nap in the back seat of his self-driving car on his way to work. Autonomous vehicles must still cross a number of barriers before they are out in force on the streets.[1] But their cousin, the autonomous mobile robot, is quietly being used in warehouses, fulfillment centers, and distribution centers around the world.

Autonomous mobile robots (AMRs) are machines that transport goods around an open space without a human controlling them. Companies like John Deere, Alibaba, and Samsung are increasingly handing over predictable and repetitive transportation tasks to AMRs. Most famously, Amazon transformed its fulfillment centers when it bought Kiva Systems in 2012. Rather than have employees walk through its warehouses to find items that customers ordered, the robots bring entire racks of inventory to employees, who then pick out the items ordered. Sales of warehouse and logistics robots are expected to rise more than 10-fold by 2021.[2]

Many logistics providers are investing in AMRs, mostly for use in sorting centers and warehouses. Others are also looking at what many see as their natural next business frontier – last-mile delivery. Robots can assist letter carriers or make deliveries by themselves, day or night.

The U.S. Postal Service (USPS), as an operator of over 200 large mail sorting centers and a delivery provider to 156 million addresses, has reason to be interested in both applications of robots.[3] In fact, the Postal Service is already testing the technology to move mail and packages between machines in a handful of sorting centers and is planning a more ambitious rollout in 2018.

This white paper describes several use cases for AMRs in postal plants and in delivery. The paper will explore the benefits and impediments to adoption and, finally, consider how the Postal Service could maximize the value of AMRs. First it is necessary to explain exactly what AMRs are, how they work, and what they can do.

State of the Technology

For the purpose of this paper, we use "autonomous mobile robots" (AMRs) as a catch-all name for any machine that:

- Moves between points without direct human guidance;

- Gathers information from its physical environment through sensors; and

- Operates indoors or on sidewalks, not on roads.

AMRs include heavy industrial equipment such as forklifts and tuggers, pickers, delivery robots, and indoor courier robots.[4] Although AMRs have been around for decades it is only more recently that they have blossomed in both form and function. Tables 1 and 2 compare a sampling of AMR offerings in logistics.

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1   The OIG recently published a white paper on how the Postal Service could incorporate autonomous mail trucks into its operations. U.S Post Service Office of Inspector General, *Autonomous Vehicles for the Postal Service*, Report No. RARC-WP-18-001, October 2, 2017, https://www.uspsoig.gov/document/autonomous-vehicles-postal-service.

2   This is compared to the 2016 baseline of 40,000 robots. Tractica, *Warehousing and Logistics Robot Shipments Will Reach 620,000 Units Annually by 2021,* March 2, 2017, https://www.tractica.com/newsroom/press-releases/warehousing-and-logistics-robot-shipments-will-reach-620000-units-annually-by-2021/.

3   U.S. Postal Service, *Postal Facts 2017,* https://about.usps.com/who-we-are/postal-facts/postalfacts2017.pdf.

4   A picker travels around a warehouse or fulfillment center and physically picks items off storage shelves and brings them to be packed. A tugger is a heavy-duty vehicle that pulls heavy loads behind it, usually in carts.

Table 1: Warehouse Robots

Company, Product	Function	Speed	Weight	Carrying Capacity	Battery Life, Recharge Time	Appearance
Effidence, EffiBOT	Follows a picker autonomously around a warehouse	4.3 mph	285 lbs	660 lbs	8 hours, 4 hours (swappable battery)	
Knapp, Open Shuttle	Transports one or two totes	4.3 mph	260 lbs	230 lbs	4 hours, 1 hour	
Seegrid, GT10 Tow Tugger	Transports carts around a facility	2.6 mph	1,860 lbs	10,000 lbs	8 hours, 8 hours	
GreyOrange, Butler XL	Lifts racks and carries them to pickers	5.6 mph	<440 lbs	3,528 lbs	8 hours, 1 hour	
IAM Robotics, Swift	Robot arm picks items while moving around on a mobile base	6.7 mph	650 lbs	50 lbs	12 hours, 7 hours (swappable battery)	

Source: OIG interviews with suppliers.

Table 2: Delivery Robots

| Company, Product	Type of Operation	Speed	Weight	Carrying Capacity	Battery Life, Recharge Time	Appearance
Effidence, PostBOT	Follows a person	3.7 mph	400 lbs	330 lbs	8 hours, 4 hours	
Savioke, Relay	Autonomous	1.6 mph	90 lbs	10 lbs	5 hours, 4 hours	
Starship Technologies	Autonomous	4 mph	50-60 lbs	20 lbs	2 hours, 45 min	
TeleRetail, One	Autonomous	5 mph on sidewalks, 20 mph on roads	40-60 lbs	100 lbs	50 miles, 5 hours	
Unsupervised.AI, Aida	Autonomous	Walks 3 mph, rolls at 15-20 mph	60 lbs	20-30 lbs	9 hours rolling or 3 hours walking, 1 hour	

Source: OIG interviews with suppliers.

The rapidly-expanding variety of AMR models can be attributed to recent developments in a few key pieces of technology.[5]

- **Sensors** – They allow robots to "see" their environment so that they can detect obstacles and navigate in open space. Cameras are one of the most common because they can detect and identify objects. Many also use a simple and inexpensive version of lidar.[6] Other sensors can include: GPS, ultrasonic sensors (which work like a bat's echolocation), and radar.[7]

- **Mapping** – Mapping technology has enabled new navigation methods that do not require infrastructure, such as magnetic tape on the floor or reflectors on the walls.[8] In the "teach and repeat" method, a person manually steers the robot along its work paths while its sensors build a digital map of those aisles; from then on, it can travel the same routes on its own.[9] More advanced, "dynamic path planning" has the robot map the entire facility. After people label objects and important areas on the digital map, the AMR can move freely about the facility, choosing the most efficient path. If one path is blocked, it can turn around and choose another.[10] Outdoor AMRs tend to rely on GPS to find their destination.[11]

- **Fleet management software** – The "brain" that oversees many AMR systems has a number of jobs, including: assigning tasks to each robot, enforcing traffic rules when multiple robots are in motion, and managing when robots charge their batteries. Fleet management software makes it possible to have operations like the Chinese sorting center in Video 1, where dozens of AMRs buzz around like ants without hitting one another. Without this software, AMRs are just "paperweights."[12]

- **Other new features** – Wheeled delivery robots cannot go up and down stairs, meaning they cannot get into most buildings and houses. One solution is a stair-climbing tread that can attach to the bottom of a robot base.[13] Another company is developing a robot that walks rather than rolls.[14] Other features available in some robots include: customer verification through facial recognition, wirelessly calling an elevator, and understanding voice commands and gestures.[15]

Video 1: Robotic Package Sorting System in China
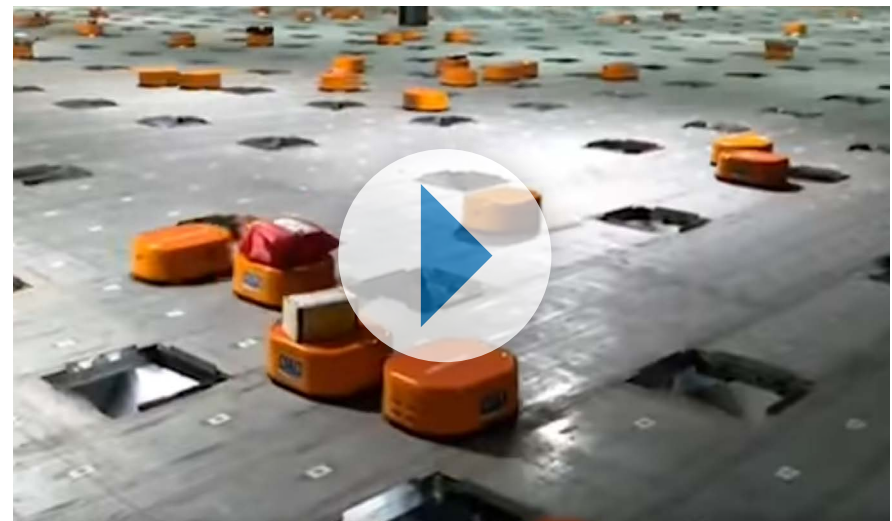
Source: Peoples Daily, China

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5   More detail about the technology can be found in Appendix A.
6   Lidar, or light detection and ranging, is a technology that fires beams of light in many directions and measures how long they take to bounce back. The rebound time of each beam tells the sensor how far away nearby objects are, allowing it to create a digital map of the robot's surroundings. Lidar is common in driverless cars.
7   Similar to lidar, echolocation is the use of sound waves and radar is the use of radio waves to determine where objects are in space by measuring how long it takes for the waves to bounce back.
8   Some indoor AMRs use laser triangulation to navigate. They bounce lasers off of reflective panels that are placed around a facility at known locations. Seeing multiple panels at a time tells the robot where it is at that moment.
9   This is the method used by the driverless tuggers at the Pennwood Place sorting facility north of Pittsburgh, where the Postal Service is running an AMR pilot. See Appendix B for more details on the Postal Service's current pilots.
10   A senior executive at Oxbotica, in discussion with the authors, November 7, 2017.
11   AMRs could manually map every city block where they plan to operate, but that would be extremely time-intensive.
12   A project manager at I IAM Robotics, in discussion with the authors, November 1, 2017.
13   A senior executive at Transcend, in discussion with the authors, November 16, 2017.
14   The startup Unsupervised.ai will begin delivery pilots with its four-legged AMR in 2018. A senior executive at Unsupervised.ai, in discussion with the authors, November 13, 2017.
15   A senior manager at JD.com, in discussion with the authors, December 4, 2017; A project manager at Savioke, in discussion with the authors, October 31, 2017; and Brittany A. Roston, "Loomo Go is an Autonomous Delivery Robot from Segway," Slash Gear, May 12, 2017, https://www.slashgear.com/loomo-go-is-an-autonomous-delivery-robot-from-segway-12485072/.

Although the pace of development in all these areas appears to be intensifying as the interest for this technology increases, the technology is still not ready for full rollout – especially in delivery. Despite indoor industrial AMRs using technology similar to outdoor delivery AMRs, indoor robots are more mature because the environment in which they operate is well-defined with fewer unknown variables, such as inattentive pedestrians, bad weather, and uneven pavement. Regulatory uncertainty and other feasibility considerations further make deployment of delivery robots difficult in the short term.

For these reasons, U.S. Postal Service Office of Inspector General's (OIG) research suggests that the Postal Service should continue giving priority to testing and deploying AMRs in sorting centers. At the same time, it could start experimenting with the possible use of delivery AMRs through a handful of small pilots, to prepare for when the market and technology are ready. Such pilots would be useful to determine the viability of the use cases within the Postal Service's unique operating environment. The following sections describe how the Postal Service could use AMRs both in sorting centers and in delivery, now and in the future, and steps they have already taken in this area. They also provide an evaluation of the factors that will affect the feasibility of these use cases.
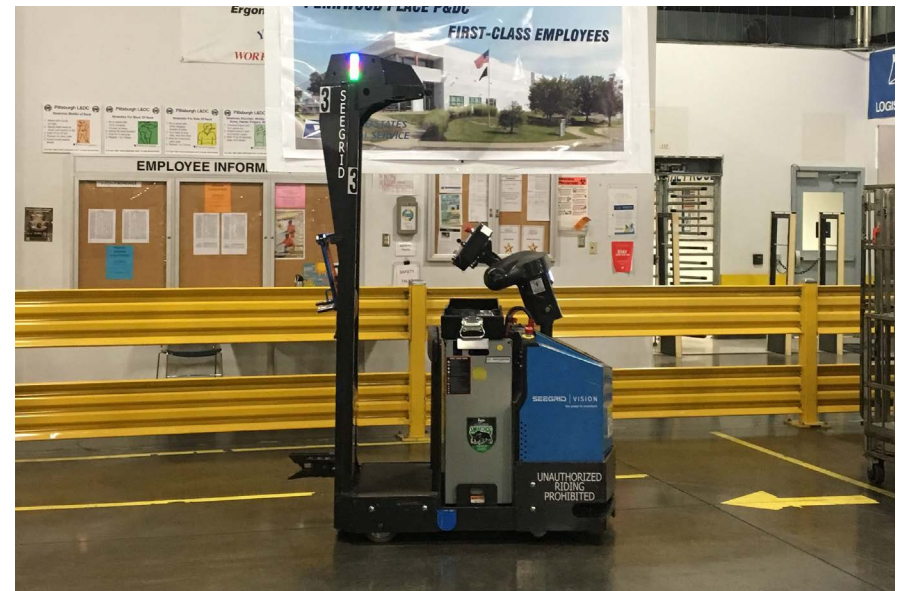
Postal Service Use Cases

Sorting Centers

For the past three decades, the Postal Service has intermittently tested different versions of AMRs to move mail within select facilities. Its efforts began in the 1980s with a pilot that used electric carts traveling along wires in the floor to automate some mail transport functions. Sporadic pilots have occurred since then, most recently at the Pennwood Place plant outside Pittsburgh.[16] In 2016, the Postal Service installed four autonomous tuggers from Seegrid for Pennwood (see Figure 1).[17] The tuggers pull up to five carts along designated routes to and from loading docks and between sorting machines.

Despite some success in achieving work hour reduction, pilots have so far represented a limited view of automation. The tuggers at Pennwood Place are manual machines with AMR technology added, enabling a human to drive it if need be. Looking forward, the Postal Service appears to be enacting an ambitious, more strategic roll-out of AMRs. The Postal Service intends to install AMRs in 25 processing plants in 2018 alone. It will test and use several types of robots from multiple vendors to evaluate which ones will work best.[18] As the Postal Service continues these efforts, it will be worthwhile to test the automation of additional tasks beyond transportation as well as test the latest generation of smaller, nimbler, and more sophisticated AMRs because of the efficiency gains further automation can bring.

Figure 1: Seegrid Tugger at Pennwood Place


Source: OIG.

Replace Manual Transport Vehicles and Tasks with Robots

The Postal Service seems to have focused its automation effort on replacing human drivers of power industrial vehicles (PIVs), employees that drive forklifts and other heavy machinery, with autonomous PIVs. This swap reduces manual driving, but driving is only one task the technology can help automate. Moving forward, other tasks that emerged from the research as candidates for automation include:

- *Hitching containers to AMRs:* the autonomous tuggers at Pennwood, for example, require a person to call them over, hitch the containers, and send them on their way. An electric hitch that needs no human intervention would allow the tuggers to hitch automatically and move on, rather than wait for a person.[19]

- *Transferring mail from sorting machines:* AMRs with robotic arms and rolling conveyers, like the Knapp Open Shuttle in Video 2, have the ability to slide bins of mail on and off sorting machines.[20] Barcode scanners would tell the AMRs where to transport the mail next. The Portuguese post is using a version of automated bin transfer, where small tugger AMRs pull bins to a stationary robotic arm that grabs them and puts them on a sorting machine.[21]

- *Moving mail on and off trucks:* loading trucks often clogs up docks, creating bottlenecks in mail flow.[22] Companies such as Wynright are developing solutions to load and unload both palletized and individual items from trailers.[23] However, crossing the threshold between dock and truck is a difficult task for AMRs.[24]

In addition to transporting mail, small AMRs could deliver tools and spare parts from back rooms to maintenance personnel in large sorting centers or vehicle maintenance facilities, cutting down on wasted walking time. FedEx is using such courier robots to bring parts to technicians at its electronics repair center in Tennessee.[25]

Video 2: Knapp Open Shuttle
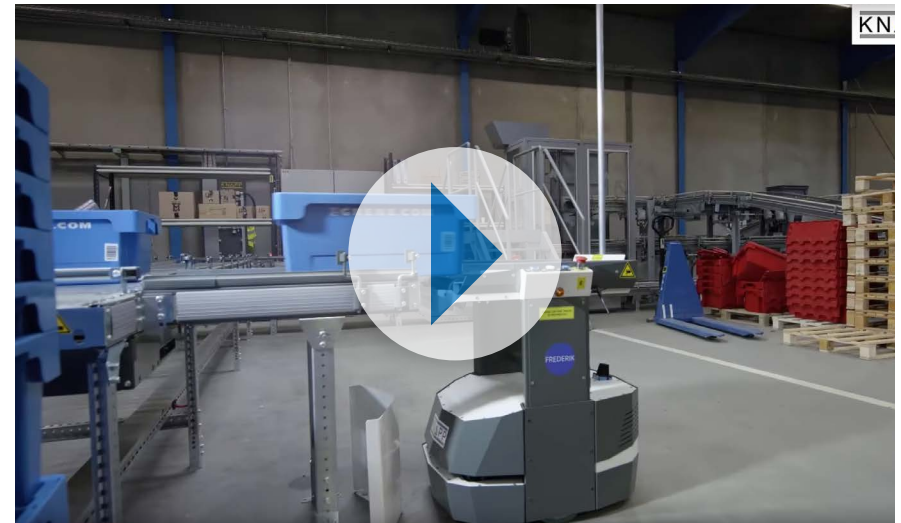
Source: Knapp AG.

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19 Companies such as Swisslog and Autoguide have either already developed or are looking into automated hitching solutions. A manager at AutoGuide, in discussion with the authors, November 2, 2017 and a senior director at Swisslog Warehouse and Distribution Solutions, in discussion with the authors, November 1, 2017.

20 A sales manager at Knapp, in discussion with the authors, November 16, 2017 and IAM Robotics, 2017.

21 CTT is working with mov.ai to develop the robotic solution, which also uses a Kuka robotic arm, to move bins of nonstandard items around the sorting center floor and onto and off machines. Research and Development personnel at CTT Portugal Post, in discussion with the authors, December 18, 2017.

22 Justin Lee, Data Collection Technician, In-Plant Support at U.S. Postal Service, in discussion with the authors, October 2, 2017 and Stephen Hagenstein, Plant Manager at Pennwood Place Processing and Distribution Center at U.S. Postal Service, in discussion with the authors, October 25, 2017.

23 Mechanized platforms that roll out of the trailer and onto the loading dock, allowing AMRs to grab pallets without leaving the dock, are another possibility. Swisslog, 2017 and Daifuku Wynright Corporation, "Truck/Container Loading and Unloading," http://www.wynright.com/products/by-system/receiving-systems/robotic-truck-unloading/.

24 Differences in truck design, size, or even tire pressure – a phenomenon common at postal docks because the Postal Service contracts out its highway transportation to many different companies – can affect the threshold between dock and truck in ways that confuse today's AMRs.

25 Mike Murphy, "FedEx is Using Autonomous Robots to Essentially Replace the Mailroom Clerk," *Quartz,* April 13, 2017, https://qz.com/955576/fedex-is-using-autonomous-robots-to-essentially-replace-the-mailroom-clerk/.

Redesign Sorting Centers for More Efficient Robotic Sorting

In the long term, benefits of AMRs go beyond reducing work hours by automating repetitive tasks to maximizing efficiency and increasing the speed of operations. Fully realizing efficiency gains requires a rethinking of current operational processes. For example, the reason that parcels are aggregated in large bins before being transported across a plant is that it is more economical, given the time transport takes, to pay an employee to move 100 parcels at once rather than individually.[26]

But an army of small conveyer robots could move smaller batches (or even individual pieces) more frequently, decreasing the time each piece spends in the plant. Imagine as soon as a package is loaded off a truck it is immediately taken by a small robot to the appropriate package sorting machine, then moved to the outbound dock right when it comes off the sorting machine. At the UPS Worldport hub in Kentucky, the 1.6 million daily packages are touched by a person only twice, allowing each one to be processed in 13 minutes on average.[27] The effects of this automation are only worthwhile if transportation is nimble enough to keep processed mail from piling up on docks waiting to go out.

Aggregating packages in smaller batches would allow the Postal Service to downsize from big autonomous PIVs to smaller AMRs that do not require such large aisles. Eliminating this empty space could in turn allow sorting centers to be downsized or allow existing facilities to process increased volumes or take on additional uses.[28] In that case, the Postal Service could turn to creative solutions like scaffolding warehousing systems (see Video 3) that use AMRs to create maximum space efficiency, even in small spaces.

Video 3: Autostore Space-Saving Warehousing System

Source: AutoStore.

Delivery

The Postal Service has been more hesitant to try delivery robots, since the business models and return on investment (ROI) are not yet proven and the technology needs to further mature to better face the challenges of moving in outdoor spaces. But OIG research suggests that there are use cases for delivery robots the Postal Service could start testing today. Below are potential applications for AMRs in delivery, both for:

- accompanied delivery, where robots transporting mail and packages would follow carriers to help them complete their job faster with less physical effort; and

- independent delivery, where robots would deliver packages to recipients directly and on their own, without a carrier accompanying them.

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26   A sales director at Otto Motors, in discussion with the authors, November 20, 2017.
27   UPS has used other forms of automation, such as conveyers instead of AMRs, to move packages quickly by removing human touchpoints. UPS, "The Incredible Numbers Behind UPS Worldport," 2015, https://compass.ups.com/ups-worldport-facts-figures/.
28   One additional use previously proposed by the OIG is to use the additional space to offer warehousing services, particularly for small businesses. OIG, *Opportunities for the Postal Service – Micro-Warehousing and Other Logistics Support Services,* Report No. MS-WP-14-003, March 13, 2014, https://www.uspsoig.gov/sites/default/files/document-library-files/2015/ms-wp-14-003_0_0.pdf.

Follow-the-carrier

How it works: To deliver packages today, mail carriers with walking routes either walk back and forth to the vehicle to grab as many as they can carry, or make a separate round of package deliveries by driving the vehicle to the houses with packages before doing a second round of door-to-door deliveries on foot for letters and flats.

A robot assistant could virtually eliminate that wasted time by carrying much larger loads. The AMR, shaped like a deep cart or large box, would ride in the back of the van until the carrier parks, fills the robot with packages, and activates its follow function.[29] Its sensors scan his body, locking on to his unique shape, clothing colors, and other characteristics. The carrier and AMR then exit the van by ramp and begin the route.

At each house, he grabs the packages from the robot and makes the delivery as usual. Heavy or cumbersome packages only need to be carried a few feet. His hands are free to grab the mail for the next delivery point. Outgoing packages picked up along the route can be put into the robot and taken back to the vehicle.

Time horizon: While fully autonomous delivery by robot will likely take longer, the Postal Service could give priority to testing follow-the-carrier robots as they could be viable for deployment within one year. This is for three reasons:

1. Technological readiness: Because it does not have to find its own way in the world, the robot needs only simple navigation technology and no localization technology. All it has to do is stay behind the carrier and not run into anything that crosses in front of it.

2. Limited operational disruption: It could fit into existing delivery operations without many changes. Carriers would maintain essentially the same routine as they have today.

3. Regulatory-friendliness: Because these robots would always have a human next to them and therefore come with fewer perceived safety risks, safety advocates would be less likely to object.

Who is using it now: Deutsche Post DHL is developing following robots for both mail delivery in Germany (the PostBOT, Figure 2) and for assisting pickers in its DHL Supply Chain warehouses.[30] Piaggio Fast Forward, a U.S subsidiary of the company that makes Vespas, has produced a following robot marketed for personal use as well as commercial delivery. The first production of 10,000-20,000 is expected in early 2019.[31]

Figure 2: DHL's Carrier-Following PostBOT

Source: Deutsche Post

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29 A park-and-loop is when carriers park a vehicle at the end of a block, walk up one side of the block delivering mail, cross the street, then deliver mail down the other side on the way back to the vehicle.
30 See Appendix C for details of this and other AMR pilots by international postal operators.
31 A senior executive at Piaggio Fast Forward, in discussion with the authors, November 15, 2017.

Autonomous Delivery from Post Offices

How it works: The Postal Service would offer a premium delivery service where customers can get their packages at their convenience. The customer registers with the app, saving her address and credit card information. When a package for her arrives at the local post office, an alert is sent to her phone asking if she wants to choose her delivery time and location for a fee.[32] If yes, she picks an available one-hour delivery window.[33]

Shortly before her delivery window, a postal employee puts her package in a robot, which receives its instructions via the app. The robot departs, traveling along sidewalks to the recipient's address. Meanwhile, the customer gets a smartphone alert when the robot leaves and when it arrives at her door. She walks outside, unlocks the robot's lid with the app, and removes her item.[34] The robot then returns to the post office for another pickup.

Time horizon: The Postal Service could potentially arrange a small pilot within a year in partnership with a robot delivery company. A handful of robots could use one post office as a hub. Any customer with a USPS.com account who lives within a 1-mile radius would get a notification to sign up for the pilot. When a package arrived for one of those customers, the robots would go to work as described above.

Even if the pilot were successful, though, the Postal Service could not do a large-scale rollout right away. These robots are not yet autonomous enough to operate without considerable assistance from a remote human operator, making the cost of delivery still quite high. The Postal Service could continue testing for another few years until the technology becomes economically viable or the Postal Service determines it is not a good operational fit.

Who is using it now: Australia Post had a recent trial near Brisbane where AMRs (Figure 3) made package deliveries between 6 p.m. and midnight after the first delivery attempt during the day was unsuccessful.[35] At the University of Arkansas, six-wheeled Starship Technologies robots brought packages from the campus post office to the dorms.[36] Chinese ecommerce giant JD.com ran similar pilots at large universities in Shanghai, Beijing, and Guangzhou.[37]

Figure 3: Australia Post's Delivery Robot

Source: Australia Post.

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32 Similar to how online retailers often pay for shipping and returns, retailers could also pay the on-demand fee.
33 This process could also be used for on-demand pickup, in addition to on-demand delivery.
34 Note that the service could only be offered to people who want packages brought directly to them. No company has yet figured out a cost-effective way to get packages out of a robot and onto a porch or mailbox without a person's help, though mechanical arms may be getting close. A senior executive at the National Robotics Engineering Center at Carnegie Mellon University, in discussion with the authors, October 26, 2017.
35 Stephanie Bennett, "Australia Post to Trial Autonomous Robot Parcel Delivery Service in Brisbane," *The Courier Mail,* October 25, 2017, http://www.couriermail.com.au/news/queensland/australia-post-to-trial-autonomous-robot-parcel-delivery-service-in-brisbane/news-story/e83db149a58ca8789c1d00101046d1ed.
36 A senior executive and other staff at Starship, in discussion with the authors, December 4, 2017.
37 JD.com, 2017.

Autonomous Delivery Direct from Stores

How it works: In addition to delivering packages processed through the postal network, the Postal Service could use robots to deliver directly from stores. Retailers would partner with the Postal Service to offer this option to their online shoppers. Customers placing an order on the retailer's website would be given the option of selecting same-day delivery, an option increasingly popular among younger shoppers, if the item is available in a brick-and-mortar store nearby.[38] These physical stores become mini fulfillment centers. Once the customer picks her preferred delivery time, her information is routed to the Postal Service, which dispatches a robot to pick up the item at the store and bring it to the customer.

Postal robots could also facilitate instant returns. In this case, the customer would order multiple pairs of boots, try them on when the robot makes the delivery, then put the unwanted boots back in the robot for return delivery to the store.[39] The Postal Service would be handling the first and last mile with one service.

Time horizon: Direct from store delivery would entail a number of operational changes since it bypasses the traditional delivery network, and, as a potential new service, may be subject to review by the Postal Regulatory Commission.[40] It would therefore take longer for the Postal Service to set up a working pilot. Nevertheless, it will be important to gain familiarity with this concept since delivery robots are poised to play a growing role in the on-demand urban delivery market in the future.

Video 4: Starship Delivery Robot
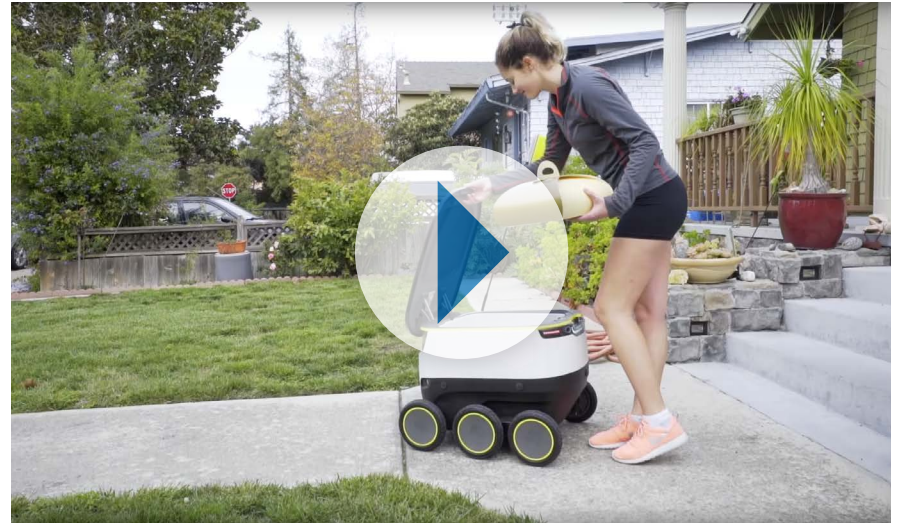
Source: Starship.

Who is doing it now: Most of the AMR delivery pilots happening today fall under this category, but with meal delivery from restaurants instead of product delivery from stores. Starship, Marble, Kiwi, Robby, and other robot makers have partnered with food delivery companies like Postmates and Doordash to test their viability. On the postal side, Swiss Post has been using Starship robots to deliver goods directly from retailers in a couple Swiss cities. In Zurich, a large department store gave Swiss Post its own room to use as a base of operations.

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38 Forrester Research asked consumers age 16-27 which of a list of value-added shopping services would make them most loyal to a brand. They chose same-day delivery by a margin of more than 20 percent. Forrester, *Raising the Bar: How Gen Z Expectations are Reshaping Brand Experiences,* May 2017, http://about.americanexpress.com/news/docs/Amex-Forrester-Gen-Z-Research.pdf, p. 7.
39 The robot could either wait for the customer to try on the product, or be summoned back to the customer's house via the app.
40 The Postal Service has sought, and received, approval from the Postal Regulatory Commission for previous pilots and market tests of new delivery services. One example is the same day package delivery program Metro Post. Postal Regulatory Commission, "Order Approving Metro Post Market Test," Docket No. MT2013-1, November 14, 2012, https://www.prc.gov/dockets/document/85644.

The Robovan

How it works: Named after a similar Mercedes-Benz prototype, the Robovan distributes packages at a much larger scale than the two previous use cases. Under this concept, a van acts as a force multiplier for AMRs by carrying many of them into a neighborhood, then releasing several at a time to make deliveries. It would only be used if the density of on-demand customers was high enough. An algorithm tells the driver where to stop, based on the addresses and requested delivery times of package recipients. Shelves in the van hold dozens of packages; at each stop the driver loads the AMRs, lowers the ramp, and sends them on their way. He drives to different stops until all the AMRs are out, then returns to pick up the AMRs at designated spots. The process repeats in a different area until all the parcels have been delivered.

Without vehicle transportation, AMRs move too slowly to make more than one or two deliveries per hour. The Robovan (in Video 5) increases their delivery rate by bringing them close to their final destination and reloading them quickly. Though letter carriers are much more efficient on an every-door basis, they cannot make eight deliveries at once like robots from a Robovan.

Time horizon: Though it seems futuristic, delivery by Robovan may not be far off technologically. Daimler, Mercedes-Benz' parent company, has committed half a billion dollars to figuring out how to move people and goods faster, including developing vans that will hold AMRs and drones.[41] It is working on fully automating the process, through a self-driving van that transports the robots while an in-vehicle parcel sortation machine loads the robots automatically. The Postal Service should continue monitoring these developments and could even proceed with piloting the Robovan concept out of a suburban post office with the right partner. Once mature, the model could improve the productivity of postal workers or enable large-scale fully autonomous delivery by AMRs. However, it would take a few years before such a service could be fully operational. In addition to the technology being sufficiently developed, the cost will need to go down significantly to make it cost-effective on a per-delivery basis. This includes

having a high-enough density of customers that would use this service for the concept to scale.

Who is doing it now: Estonia's postal service, Omniva, piloted a Robovan in Tallinn in 2017. Eligible customers coordinated delivery via text. Omniva employees drove the Robovan through neighborhoods to release Starship robots for delivery. Starship trained the drivers and handled the logistics of where to stop the van on each route. In all, 1,166 package deliveries were made over the course of 3 months.[42]

Video 5: Mercedes-Benz Robovan Concept

Source: Mercedes-Benz.

Implementation Considerations

The OIG conducted nearly 50 interviews with AMR suppliers, industry groups, postal operators, academics, and postal stakeholders to determine what impacts mobile robots would have on the Postal Service's unique ecosystem.[43]

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41   Kristin Korosec, "Here's Why Mercedes is Betting on Drones and Self-Driving Robots," *Fortune,* September 7, 2017, http://fortune.com/2016/09/07/mercedes-vans-drones-matternet/.
42   A board member at Omniva, in discussion with the authors, December 12, 2017.
43   For a full list of interviews, see Appendix E.

Impact on Operations

Technical Limitations Impact Predictability and Scalability in the Short Term

AMRs function best in structured, standardized environments. Unpredictable settings remain a challenge. Current delivery robots only operate at 70-90 percent autonomy, turning control over to a remote operator at crosswalks or unfamiliar scenarios.[44] Advanced functions like task prioritization and rerouting to avoid obstacles are relatively new, making them more expensive and less tested.[45]

Even in more controlled settings like postal facilities, AMRs' lack of decision-making ability turns small impediments into constant problems, which creates unpredictability. For example, although tablets at the Pennwood Place facility inform employees when an autonomous tugger will arrive at their station, the timer cannot account for a tugger sitting helplessly behind a box waiting for someone to rescue it.[46]

AMRs can certainly work in postal facilities, but their current configuration is not ideal. Sorting centers tend to have different layouts and processes, making a standardized AMR solution more difficult. Many do not have aisles wide enough to safely accommodate robots and employees.[47] And while robots are best at consistent, continuous operations throughout the day, work at postal facilities tends to fluctuate based on volume.[48] Mail delivery also lacks standardization, since items must be placed in porch mailboxes, curbside mailboxes, and community clusterboxes of all sizes – a confusing diversity of conditions for a robot.

Rethinking Concept of Operations Creates Long-term Efficiency Gains

The low-hanging fruit offered by AMRs is their potential to reduce work hours by automating repetitive transportation tasks. However, there is additional opportunity for larger efficiency gains by automating more tasks, redesigning sorting centers to optimally use AMRs, and rethinking the concept of operations to leverage more sophisticated and nimble robots. For example, moving from large batch processing to small and even individual item processing by using smaller robots as previously described, could significantly speed up mail processing.[49] Video 6 provides a clue about how the speed of operations can change.

Video 6: Individual Item Movement Concept of Operations
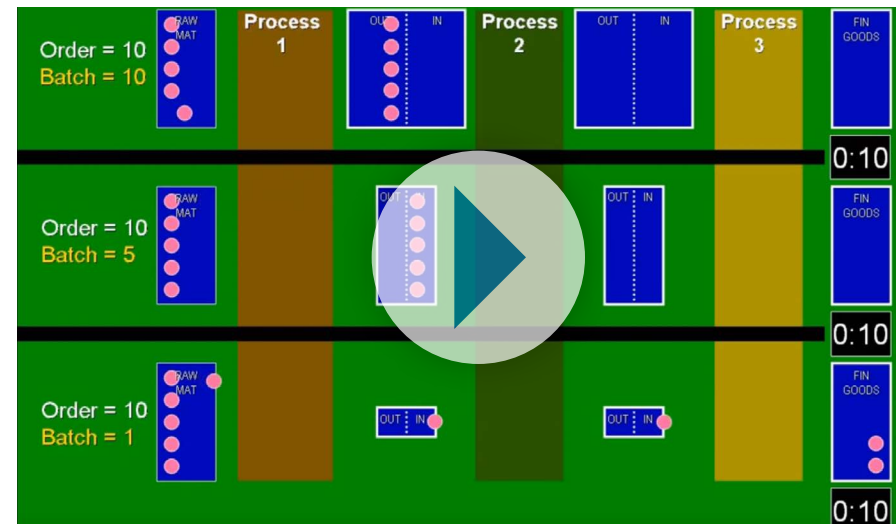
Source: BMGI.

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44 Companies would eventually like to achieve 99 percent autonomy, meaning one remote human operator could monitor 100 robots at a time. Starship, 2017.
45 Tasks such as identifying, grasping, and manipulating objects also remain difficult for robotic arms, although the durability and regular shape of mail and parcels may make them easier for robots to grip than other objects. Otto Motors, 2017 and a director at SRI International, in discussion with the authors, November 17, 2017.
46 Another problem is that if all AMRs are out on assignments, the system cannot determine when one will be free.
47 Aisles need to be at least 10 feet wide for safety and ease of turning. Only 30 facilities currently have aisles wide enough for immediate testing, but it is possible to widen the aisles at other facilities by moving equipment around. Sparks, 2017.
48 Mark Bieranowski and Joan Baker-Spanos of USPS, in discussion with the authors, September 11, 2017 and Austin Bouchard, Mechanical Engineer in Network Operations at USPS, in discussion with the authors, December 11, 2017.
49 Batching is considered inefficient in lean processing systems because, although items spend the same amount of time actively being processed, time is wasted while items sit around waiting to be batched rather than moving on immediately to the next point of processing. See, for example, Venanzio Figliolinio, "Why Do We Batch?," https://leansixsigma.community/blog/view/367/why-do-we-batch.

The Postal Service has already seen how simpler AMRs can affect the speed of operations. When it installed autonomous tuggers at a Brooklyn plant in the early 2000s, processing time for flats dropped from 10 hours to about four.[50] If the current concept of operations would be automated to reduce the number of times postal employees touch a parcel as it moves through a plant, the process would run much more smoothly. Each touchpoint, from moving pallets, to dumping mail onto conveyor belts, to moving mail between machines, is a moment that is slowing down the process.

Speeding up operations is important in the face of increasing package volume due to ecommerce growth. BI Intelligence predicts that in 2020, US ecommerce sales will total $632 billion, up from $385 billion in 2016.[51] The Postal Service may need to expand its infrastructure unless it can increase the throughput of its existing infrastructure. DHL is expecting to double the volume at its Memphis logistics warehouse by the end of 2018, but by leveraging AMRs that assist pickers and increase their productivity, they plan to absorb the increase without adding more space or workers.[52]

Clearly, these wider efficiency gains will take longer to realize - it is operationally less challenging to replace a manual task with an AMR that does the same task than it is to completely redesign a concept of operations to be more AMR-centric.

For last-mile delivery, robots that follow carriers would also provide efficiency gains. Carriers would no longer need to make trips to and from the vehicle to fetch packages, and their hands would be free to gather the mail for the next delivery point while they walk. And by physically exerting themselves less, they can keep a brisk pace throughout the day.

Economic Feasibility

Up-front Cost Makes Implementation Expensive

The purchase price of indoor AMRs can be quite high, although buying in bulk could provide a discount.[53] Autonomous PIVs may cost $200,000 – 20 times more than their manual counterparts.[54] Smaller robots come in under $100,000 and can be as low as $10,000, but you have to buy more of them to handle high volumes.

Unlike companies that sell indoor robots, most companies that make delivery robots prefer to offer "robots-as-a-service," where partners like the Postal Service would lease the robots on a per-delivery or subscription basis while the manufacturer owns, operates, and maintains them.[55] This market is still developing, however, so that model could change, especially if the Postal Service made a bid to buy a large number of robots.

The other cost associated with delivery robots is the cost per delivery. The cost of each delivery Swiss Post makes in its deliver-from-store pilot is currently extremely high. The good news is that the majority of that is the cost of the handler that walks with the robot.[56] As regulators allow AMRs to travel without chaperones, associated salary costs will shrink dramatically. The upfront cost of the technology is already coming down. Robots made by Chinese ecommerce giant JD.com originally cost $88,000; less than one year later the cost dropped to about $7,000.[57]

50   Maravas, 2017.
51   BI Intelligence, *National Retail Federation Estimates 8-12% US E-Commerce Growth in 2017,* February 10, 2017, http://www.businessinsider.com/national-retail-federation-estimates-8-12-us-e-commerce-growth-in-2017-2017-2.
52   A robotics researcher at DHL, in discussion with the authors, November 28, 2017.
53   The purchase price will depend on the specific technology used on the AMRs, the robot's capacity, and the specific purchase package (including software, training, and maintenance options).
54   The Seegrid tuggers purchased by USPS cost $200,000, while regular tuggers cost just $10,000. Bieranowski and Baker-Spanos, 2017 and Hagenstein, 2017.
55   Both Starship and Dispatch operate on this model. Starship, 2017 and Kia Kokalitcheva, "This Cute Self-Driving Robot Wants to Deliver Your Food or Laundry," Fortune, April 6, 2016, http://fortune.com/2016/04/06/dispatch-carry-delivery-robot/. Some companies making AMRs for sorting centers and warehouses have options to lease robots in the short term. However, their focus seems to be on selling systems outright rather than the robots as a service model preferred by delivery robot manufacturers. One company reported that it was thinking about allowing customers to scale up and down based on seasonal changes to offer more flexibility, but had not found a way to do it that worked for both supplier and customer. A senior executive at Vecna, in discussion with the authors, November 20, 2017.
56   Removing the cost of the handler puts the model on competitive footing with other same day delivery services in Switzerland. Autonomous delivery researchers at Swiss Post, in discussion with the authors, December 11, 2017.
57   Echo Huang, "In China, a Robot Has Started Delivering Packages to People," *Quartz,* June 19, 2017, https://qz.com/1009155/chinas-second-largest-ecommerce-company-jd-jd-just-used-a-robot-to-deliver-packages/.

AMRs Generate Labor Cost Savings in the Long-Term

The Postal Service has announced its intention to cut total work hours by 23 million in fiscal year (FY) 2018.[58] Indeed, work hour reduction was singled out as a top driver of renewed interest in sorting center robots going forward.[59]

Figure 4: Labor Cost Savings at Pennwood Place So Far
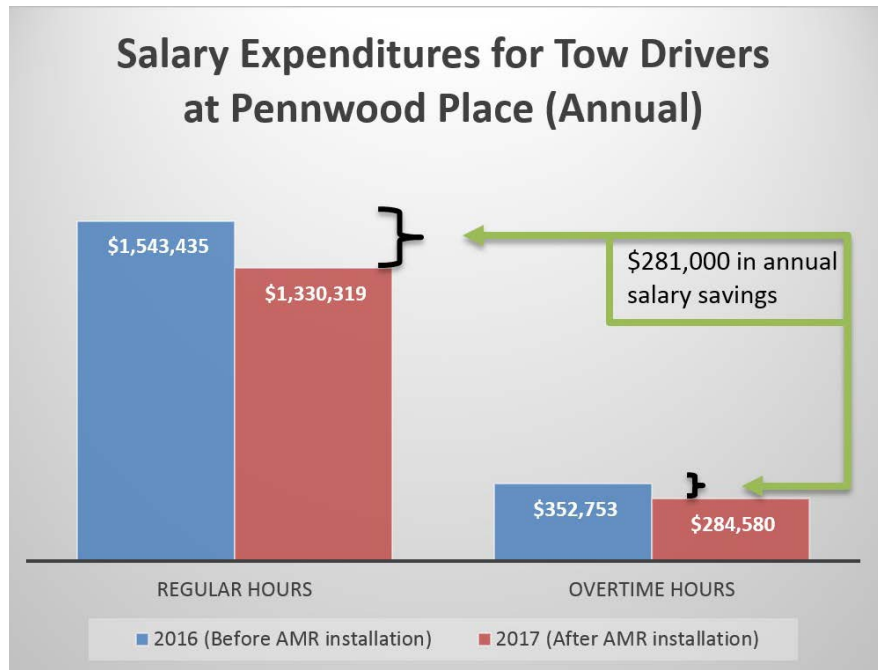
Source: OIG.

For previous pilots, the intention was to test the technology and not necessarily to save work hours. However, the Pennwood Place pilot holds a clue to how AMRs will impact labor costs.[60] From its start in April 2017 through November 2017, total regular hours worked by tugger drivers fell by 14 percent compared to the same period in 2016. Overtime hours, for which employees are paid time-and-a-half, fell by 19 percent. This reduction produced the equivalent of $281,000 in annual savings.[61] A second round of payroll reduction would come from not filling the vacancies left by retiring PIV drivers.[62] This puts the Postal Service's return on investment (ROI) at about 3 years, based on the approximate $200,000 price tag for each of the Seegrid tuggers.[63] This is roughly in line with the ROI that other logistics companies have reported.

Labor cost savings generated by delivery AMR pilots are so far non-existent or negative, although they were never intended for that purpose.[64] In the future, follow-the-carrier robots could reduce overtime payments by helping carriers finish their routes on time. City carriers worked more than 53 million hours of overtime in FY 2017, costing the Postal Service $1.95 billion.[65] Autonomous delivery robots may never be cheaper than mail carriers; they move slowly, deliver only one package at a time, and could reach only a tiny fraction of this country's 156.1 million delivery points each day (unless the Postal Service used a substantial number of Robovans).[66] They make more sense as a potential revenue generator – through customers paying extra for on-demand delivery.

Labor Considerations

New Skills Will Require Employee Training and Re-Training

AMRs, like all automation, reduce the need for certain skillsets like repetitive motion tasks and create a need for others, while creating new opportunities to expand the business. The exact number of jobs that will be lost and gained is so

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58 U.S Postal Service, *Fiscal Year 2018 Integrated Financial Plan,* 2017, http://about.usps.com/who-we-are/financials/integrated-financial-plans/fy2018.pdf, p. 7.
59 Sparks, 2017.
60 Bouchard, 2017.
61 Total hours worked for the period fell by 5,071 during the period from 4/8/17-11/30/17 compared to the same period the previous year, before the tuggers were introduced. Tugger operators get paid an average $27.29 per work hour (not including benefits, to account for the fact that non-career workers get very few benefits). That equates to $213,000 per year. Overtime was paid at $40.9 per hour ($27.29 x 1.5). At 1,081 OT hours saved during the pilot, that totals $68,000/year.
62 Pennwood's four autonomous tuggers reduced regular work hours by the equivalent of nearly four full-time PIV drivers. In FY 2017, full-time employees in this category received an average of $74,000 in annual pay and benefits.
63 This ROI calculation includes only the aforementioned labor cost savings and the purchase price of the robots. It does not account for other factors, such as the additional time that other employees may have to spend handling the AMRs, or the efficiency changes that AMRs may bring.
64 Omniva, 2017 and an autonomous delivery researcher at Australia Post, in discussion with the authors, January 26, 2017.
65 U.S. Postal Service, *National Payroll Summary.*
66 U.S. Postal Service, *Postal Facts 2017.*

far unclear. Amazon, for example, credits its heavy investment in robots with the construction of several new fulfillment centers and the accompanying hiring of 50,000 new employees.[67] The U.S. itself is in a period of record automation, yet unemployment is near a 17-year low.[68] Although this is an encouraging sign for postal employees, the threat of job elimination still creates some apprehension.

Although, jobs involving repetitive tasks will likely be eliminated, union contracts protect employees from being fired and replaced by AMRs. As such, postal workers will need to be retrained to perform new tasks, such as programming, maintaining, and working with AMRs, and new hires may be required to have particular high-tech skills. AMRs can also enable new services and processes that will, in turn, create new jobs that no one has yet thought of, in the same way that the internet created new jobs in search engine optimization, for example.[69]

It will therefore be crucial to get employees to buy in to what the Postal Service is doing and why. This means educating and training employees, showing them how the robots can make their jobs easier by improving their productivity, easing their load, and allowing them to do more value-added tasks.[70] Terms like "cobots" are sometimes used to describe the human-machine interaction to produce better outcomes.[71]

So far, postal employee buy-in of AMRs has been mixed. At Pennwood Place, PIV drivers complained about getting stuck behind slow AMRs, which made their jobs more difficult. When wi-fi problems at the plant caused the robots to stop working for a brief period, however, other employees expressed disappointment because they had come to rely on the robots.[72] It should not be surprising that in the past, employees at both the Postal Service and elsewhere have resisted or hindered their AMR "coworkers."[73] Continued management-staff communication and collaboration before, during, and after the AMR roll-out phase will be a key success factor.

AMRs Can Create a Safer Work Environment for Employees

In addition to improving worker productivity, AMRs can improve their health and safety. AMRs that follow letter carriers would prevent them from carrying awkward or heavy boxes, reducing the number of back or knee injuries. The secondary benefit of a healthier workforce would be less missed time and fewer workman's comp payouts. Additionally, the high turnover rates of non-career city carriers might fall as the job becomes less physically demanding, meaning the Postal Service loses less expertise and spends less on hiring and training new employees.[74]

When it comes to sorting centers, autonomous PIVs would reduce injuries caused by distracted or careless driving.[75] The sensors on mobile robots are never distracted and, thanks to industry safety standards, move slowly enough (often less than 5 mph) to stop immediately when a person walks in front of them. Seegrid reports that its AMRs have driven 650,000 miles without any accidents.[76]

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67   Evelyn M. Rusli, "Amazon.com to Acquire Manufacturer of Robots," *New York Times*, March 19, 2012 https://dealbook.nytimes.com/2012/03/19/amazon-com-buys-kiva-systems-for-775-million/.
68   Automation is often blamed for the country's stagnant wage growth, however. A senior executive at the Association for Advancing Automation, in discussion with the authors, November 20, 2017.
69   SRI, 2017.
70   Many AMR makers offer free training for workers at their customers' warehouses, such as Seegrid's Robotics Training Program. Nye Longman, "Embracing Automation: Preparing the Workforce to Collaborate with Robots," *Supply Chain Digital,* May 12, 2017, http://www.supplychaindigital.com/technology/embracing-automation-preparing-workforce-collaborate-robots.
71   Many picking robots designed for ecommerce fulfillment are designed to work with a human picker. This aligns with research regarding there being a "sweet spot" combination of human-machine interaction that produces a better outcome than full automation. Myers, 2017 and DHL, *Robots in Logistics: A DPDHL Perspective on Implications and Use Cases for the Logistics Industry*, March 2016, http://www.dhl.com/content/dam/downloads/g0/about_us/logistics_insights/dhl_trendreport_robotics.pdf.
72   Bieranowski and Baker-Spanos, 2017.
73   Hagenstein, 2017 and SRI, 2017.
74   Non-career city carrier positions had a 60 percent turnover rate in FY 2016, while non-career rural carriers only turned over at 35 percent. One of the major differences between the two jobs is that city carriers spend much of their route walking while rural carriers spend most of theirs in a vehicle. OIG, *Non-Career Employee Turnover,* Report No. HR-AR-17-002, December 20, 2016, https://www.uspsoig.gov/sites/default/files/document-library-files/2016/HR-AR-17-002.pdf.
75   Eighty-five people are killed and another 96,700 injured in forklift accidents every year in the United States – an injury rate almost 13 times higher than that for motor vehicles. Forklift injury rate of 11.3 percent, based on about 855,000 forklifts in operation, compared to an injury rate of 0.77 percent for highway vehicles (based 32,000 deaths and 2 million injuries per 264 million highway vehicles). Optimum Safety Management, *Forklift Safety: Facts, Stats and Tips for Safe Operation,* July 1, 2015, https://www.oshasafetymanagement.com/blog/forkliftsafety-infographic/ and Centers for Disease Control and Prevention, *Motor Vehicle Crash Deaths,* 2016, https://www.cdc.gov/vitalsigns/motor-vehicle-safety/index.html.
76   Katie Burke, "Turning Auto Plants into WALL-E Worlds," *Automotive News*, May 28, 2017, http://www.autonews.com/article/20170528/OEM06/170529829/turning-auto-plants-into-wall-e-worlds?X-IgnoreUserAgent=1&X-IgnoreUserAgent=1.

Existing Regulation

Regulation for Delivery Robots is Sparse, Creating Uncertainty

Because delivery robots are new to city streets, regulations governing them are still sparse. There has been no attempt to regulate them on the federal level. Locally, five states and a handful of cities have explicitly permitted them, albeit with restrictions on their size, speed, and areas of operation.[77] Notably, the District of Columbia opened city sidewalks up to testing in late 2016 – so long as the robots followed the District's 50-lb weight limit, 10-mph speed limit, and had a human chaperone alongside them at all times. Since then the city council has tried to expand the law into a permanent, less restrictive version.[78]

The OIG is aware of only one municipality that has severely restricted outdoor AMRs. In December 2017, San Francisco passed a bill that limits delivery robots to 3 mph, to testing only, and only in small industrial areas of the city. The councilman who sponsored the bill cited San Francisco's crowded sidewalks, pedestrian safety (especially of the elderly and disabled), privacy concerns surrounding the robots' cameras, and labor displacement as areas of concern.[79] Any delivery robot fleet that operates nationally, including a postal fleet, could struggle to comply with varying local ordinances concerning size, weight, and speed. Additionally, government tolerance of delivery robots may change as they begin to proliferate on city sidewalks, inevitably drawing criticism from some citizens.

Public Perception

Customers Believe Autonomous Delivery Would Improve Customer Service

To understand the public's perception of AMRs and how it would react to the Postal Service potentially deploying AMRs for delivery, the OIG administered a nationally representative online survey.

The survey revealed that despite being initially less familiar with the concept, over 80 percent of respondents believe delivery robots will be in use with within the next five years.[80] The survey also discovered that more respondents like the idea of delivery AMRs than dislike it, particularly when it comes to robots that help the carrier.[81] Most people have no preference between whether a robot or a carrier makes a delivery, and a few would actually prefer a robot delivery service.[82]

Figure 5: Percentage of People that Like and Dislike Robotic Delivery Concepts
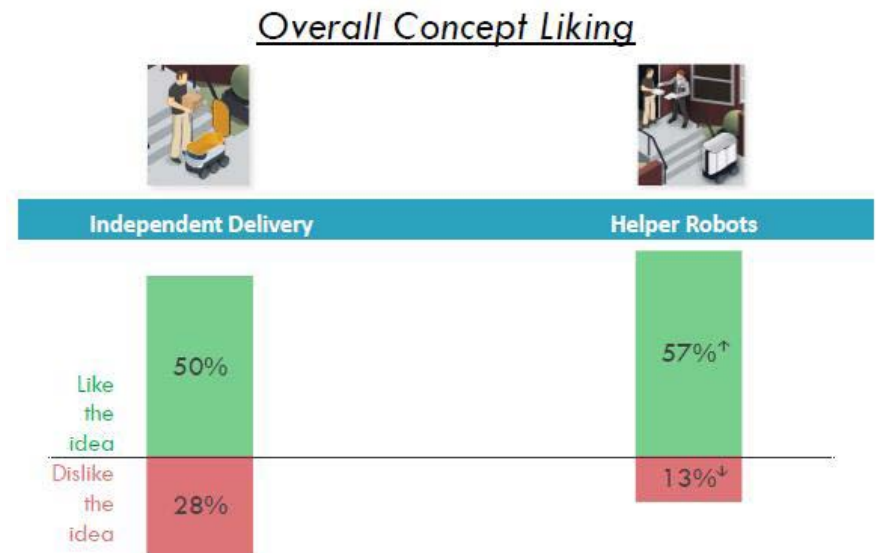
Source: OIG.

Customers are receptive to delivery AMRs because they provide a higher level of service, with flexibility, speed, and security being important factors. AMRs

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77   Currently Virginia, Ohio, Wisconsin, Idaho, and Florida have passed delivery robot legislation. A table summarizing all state and some metropolitan area legislation can be found in Appendix D.

78   Proposed legislation would, for example, loosen insurance requirements and increase the maximum allowable weight of a delivery robot to 90 pounds. A policy analyst at District Department of Transportation, in discussion with the authors, November 7, 2017.

79   A legislative aide at the Office of Supervisor Norman Yee, in discussion with the authors, November 16, 2017.

80   This was true for both AMRs that followed a carrier (84 percent) and AMRs that enabled fully autonomous delivery (81 percent). The inevitability of robot-based delivery is also supported by Pew Research Center, which found 65 percent of survey-takers responded "probably will" or "definitely will" to the question "Most deliveries in cities will be made by robots or drones instead of humans." OIG, *Public Perception of Delivery Robots in the United States*, Report No. RARC-WP-18-005, April 9, 2018, https://www.uspsoig.gov/document/public-perception-delivery-robots-united-states and Pew Research Center, *What Americans Expect the Future of Automation to Look Like,* November 16, 2017, http://www.pewresearch.org/fact-tank/2017/11/16/what-americans-expect-the-future-of-automation-to-look-like/.

81   For fully autonomous delivery, 50 percent of respondents like the concept compared with 28 percent that dislike it. Fifty-seven percent like the helper robots, but only 13 percent dislike that concept. OIG, 2018.

82   Seventy-one percent of respondents had no preference for delivery by a person compared to delivery by a robot, and five percent reported that they would always prefer delivery by robot. OIG, 2018.

can deliver to any address at any time, allowing customers to get their mail and parcels potentially faster and when it is convenient.[83] Missed deliveries and package theft from porches would be a thing of the past. Customers would also enjoy greater visibility into their deliveries, tracking robots through an app much like Uber. Using such innovative technology would improve brand positivity for the Postal Service and lead more people to think of it as an innovative company, particularly when it comes to helper robots that follow carriers.[84] Real-world delivery pilots, such as in Estonia, have also found customer satisfaction with the service.[85]

While most of the sentiment toward delivery AMRs is positive, there is a sizable minority of people who could be considered anti-robot. One-quarter of respondents to the OIG survey would always prefer a human to deliver their items, even if robots were faster *and* cheaper. Furthermore, accidents involving robots, while extremely rare, are high profile. Take for example the news coverage of the mobile robot that collided with a toddler or the security robot that fell into an office fountain.[86] Such an incident caused by a postal delivery robot could be harmful to the brand.[87]

Vision for the Future

Given the rate at which AMR technology is developing, AMRs are set to play a larger role both in operations and delivery. It is important that the Postal Service prepare for a future where postal logistics may look very different than it does today by proactively investigating how to best use AMRs to further promote efficiency, innovation, and quality of service. Specifically, as the Postal Service moves forward it will be important to:

- **Take a systematic approach to testing indoor AMRs.** Thus far, the Postal Service's pilots do not appear to have been conducted as part of a strategic plan. Each seems to have been a one-off experiment that had little

influence on any other. Now that the Postal Service plans to put mobile robots in 25 sorting centers in 2018, it is vital that the installations be done in an organized fashion. Pilot goals should be clear, communicated to all involved parties, and align with the pilot's design. If the goal is to compare different types of AMRs, then centrally document their strengths and weaknesses to inform future purchases. If the objective is to reduce work hours, then design each pilot to prioritize work hour reduction over other factors, like mail processing speed. Priorities will impact what technology is purchased and what operational changes are made.

- **Maximize the effectiveness of indoor AMRs.** Effectively using both large and small AMRs will require the Postal Service to rethink the layouts of sorting centers. Currently, only 30 out of 227 processing and distribution centers have aisles wide enough to accommodate two-way traffic of the larger autonomous PIVs.[88] Unless the Postal Service wants to make its aisles into one-way streets, it will have to move sorting machines around inside the other plants to create wide enough aisles. If the Postal Service determines, based on appropriate cost-benefit analysis, that using more sophisticated AMRs to increase speed and throughput makes the most sense in the long term, it will also need to give careful thought to the sorting center layout that best suits that new concept of operations. In addition, the Postal Service should also consider the efficiency benefits of buying standardized mail containers designed to work with AMRs, allowing the same robot types and the same processes to be deployed across many facilities. Standardization of the facilities themselves, though a far more ambitious ask, would have an even greater impact with the potential to save one-third to one-half the cost of a robot rollout.[89]

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83 Increasing throughput in sorting centers (and removing other bottlenecks) also helps put packages in customers' hands faster.
84 This effect is not unique to the Postal Service, and all brands tested in the survey (the Postal Service, FedEx, UPS, and Amazon) would benefit from brand positivity. In addition, Amazon and UPS are better trusted by customers to implement both helping and fully autonomous AMRs, but more people trust the Postal Service than FedEx to implement helper robots. OIG, 2018.
85 In Estonia, the robots were often delayed by excited customers taking selfies with them. Some residents who had heard about the pilot were disappointed that their street wasn't included, so they entered the address of a local supermarket as their delivery address, then waited to greet the robots at the front entrance. Omniva, 2017.
86 James Vincent, "Mall Security Bot Knocks Down Toddler, Breaks Asimov's First Law of Robotics," *The Verge*, July 13, 2016, https://www.theverge.com/2016/7/13/12170640/mall-security-robot-k5-knocks-down-toddler and James Titcomb, "Security Robot 'Drowns Itself' in Office Fountain," *The Telegraph,* July 18, 2017, http://www.telegraph.co.uk/technology/2017/07/18/security-robot-drowns-office-fountain/.
87 Ed Brinckman, Delivery Strategy and Planning at U.S. Postal Service, in discussion with the authors, December 12, 2017.
88 Sparks, 2017.
89 NREC, 2017.

- **Re-align the postal value chain to maximize efficiency.** Speeding up mail processing operations within postal facilities is not useful if the other components of the value chain, especially transportation, are not aligned with the faster pace of sorting operations. For example, if mail is processed faster but then piles up at the loading dock waiting for transportation to take it away, the efficiency gained with AMRs is quickly lost. Speedier AMRs must be coupled with more frequent truck arrivals to get the mail out the door faster. Altering transportation will be key to translating higher throughput at the plants into faster delivery times. Another example of network realignment comes from disrupting the traditional "post office-to plant-to post office" mail processing system. Small, modular robotic sorting machines, like the t-Sort from Tompkins Robotics, enable the sortation of items in any small open space, including the back room of a post office. Mail and packages collected for local delivery could be processed on site without ever leaving the ZIP code, and ecommerce returns could be sorted into a few buckets that are sent directly to the Postal Service's major reverse logistics partners (Amazon, FedEx, and Newgistics).[90] Bypassing the hub-and-spoke network would reduce processing time.

- **Begin testing delivery AMRs.** The Postal Service could start by testing the more easily implementable follow-the-carrier AMRs in small areas near post offices, as Deutsche Post is doing, to determine how easy they are for carriers to handle and how reliably they work. Given the unique operating environment of the Postal Service, these pilots will be useful to determine if delivery AMRs are worth pursuing at USPS. If they get high marks, the Postal Service could modify a few of its delivery vans to allow the robots to ride in them and gradually expand the pilot scope. Considering that robots may play a growing

role in the on-demand, urban delivery market in the future, the Postal Service could also explore an on-demand autonomous delivery pilot (such as delivery from post office or from store) to assess how much customer interest exists for a premium service like this, what the revenue potential might be, and what would be the unforeseen challenges.

- **Work closely with partners and suppliers.** DHL purposefully tests new technologies early, allowing it to steer its partners toward creating products that are more customized to its needs.[91] Sponsored robotics challenges, of the kind offered by Amazon and DHL, offer opportunities to develop AMRs without a large investment in research and development.[92] The Postal Service could also partner with university robotics labs to explore what models and features would work best for the Postal Service, similar to how it is working with the University of Michigan to build its prototype autonomous rural delivery vehicle.[93] In the deployment phase, it may consider business models like robot-as-a-service, where the robots would be leased from a technology provider to reduce investment costs.

- **Increase coordination capabilities.** A postal delivery network that incorporates an increasing array of automated methods of delivery, such as autonomous vehicles, robots, and drones will require parallel investments in software tools able to efficiently coordinate them. AMR startup TeleRetail's plan for Swiss Post includes drones that fly packages to remote mountain villages and drop them at mechanized heliports where robots carry them the final leg to people's houses.[94] Coordinating such a multi-modal delivery network requires systems and capabilities to effectively and incrementally integrate each new technology into the network. These coordination tools will be the topic of future research by the OIG.

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90   A senior executive at Tompkins International, in discussion with the authors, November 2, 2017.
91   DHL, November 2017.
92   Technology providers compete in company-sponsored robotics challenges to solve a specific problem or issue experienced by the sponsoring company. For examples of such challenges, see: DHL, "DHL Robotics Challenge 2017," https://www.dhlinnovationchallenge.com/roboticschallenge/ and Amazon, "2017 Amazon Robotics Challenge Official Rules," 2017, https://www.amazonrobotics.com/site/binaries/content/assets/amazonrobotics/arc/2017-amazon-robotics-challenge-rules-v3.pdf.
93   OIG, 2017.
94   A senior executive at TeleRetail, in discussion with the authors, November 2, 2017.

Conclusion

The Postal Service has already run successful pilots of AMRs in sorting centers, and plans more for the coming year. These pilots have already demonstrated work hour reductions. In the long term, the Postal Service could expand the scope of these pilots to test how AMR technology can enable a new concept of operations that generates further efficiency gains. In addition to testing the technology, the pilots should be used to conduct a cost-benefit analysis and assess the potential ROI.

When it comes to delivery, the Postal Service has been less active. Delivery presents a more complex environment that the technology is not yet developed enough to autonomously handle, and the market for robot-based delivery is immature. Nevertheless, the Postal Service can continue monitoring and begin experimenting with relevant business models through small-scale pilots, while technological and market development continue. AMRs that follow the carrier and hold heavy packages for them as they walk their routes could be piloted right away, with little operational disruption, and should be of interest to both carriers and postal management.

Logistics and delivery companies around the globe are already investing in research and development of AMRs for both processing operations and delivery. It is important that the Postal Service do the same and continue evaluating how these technologies can help increase efficiency and innovate the postal network of the future.

The first AMR actually dates back to the 1950s. The "Guide-O-Matic" tow vehicle was attached to wires, first on the ceiling and later in a slot in the floor, through which it received signals that sent it to its destination.[95] Many AMRs in use today do not seem very different from the Guide-O-Matic; the most basic ones are boxy machines that pull carts from point A to point B. Autonomous tuggers look like traditional manual tuggers, and autonomous pallet jacks look like traditional manual pallet jacks.

But the range of AMR options has blossomed in recent years, in both form and function. AMRs are being used in fulfillment centers to lead pickers to the right item on the right shelf, or, as in Amazon's case, bringing racks of items directly to the picker.[96] Then there are mobile robots that use grippers to do the picking themselves. AMRs can pull bins off shelves, roll them on and off conveyor belts, and put them back on shelves. They are being used to bring meals to hotel rooms and packages to people's homes. There are robots that patrol Shell refineries checking for gas leaks, and others that patrol corporate campuses looking for intruders.

The rapidly-expanding variety of AMR models can be attributed to recent developments in a few key pieces of technology.

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95 Bob Trebilcock, "Let's Remember Mac Barrett, Father of the AGV," *Modern Materials Handling,* August 23, 2010, http://www.mmh.com/article/lets_remember_mac_barrett_father_of_the_agv.
96 To see how Amazon's robots work, see Erico Guizzo, "A Look Under the Hood of Kiva systems Warehouse Robots," *IEEE Spectrum,* July 2, 2008, https://spectrum.ieee.org/automaton/robotics/robotics-software/a_look_under_the_hood_of_kiva_systems_warehouse_robots.

Management's Comments:

Management acknowledges that they agree with the overall findings of the OIG report, but disagree about the potential of certain use cases of AMRs in delivery. Specifically, they note that an AMR such as DHL's PostBOT would not fit in the Postal Service's current model of delivery vehicle and that environmental factors such as weather, pavement conditions, and the presence of pedestrians could limit their utility. Management does agree that there is potential to test a follow-the-carrier AMR on a walking route.

Management also believes that autonomous delivery applications are too immature to handle routine activities, such as crossing streets, without the aid of a human chaperone, and are further concerned about the limited range of these AMRs. Management also expresses concern about the current cost of delivery AMRs as well as the regulatory framework surrounding the use of such devices. Nevertheless, management says they are still interested in the technology and will continue to monitor its development.

Evaluation of Management's Comments:

The OIG appreciates management's comments and their willingness to continue to monitor and study the technology. Monitoring and experimenting is indeed the main suggestion of this paper, which presents use cases of potential interest to the Postal Service based on our interviews with developers and users of the technology. The OIG understands that the full operational impacts are not entirely understood. This is why it does not suggest the implementation of the technology today but rather suggests piloting, which would help clarify these operational issues and determine whether the benefits outweigh the challenges and costs. As management indicates, testing a follow-the-carrier robot on a walking route may be a good place to start. Ultimately, it is up to the Postal Service to determine which use cases to pilot based on its interests and priorities.

Additionally, the OIG suggests collaborating with suppliers to design solutions that work specifically within the Postal Service's own unique operating environment. This would include some of the design elements that management expresses concern with, such as that a PostBOT, as currently designed for DHL, is not able to fit in the current postal vehicles. The OIG believes the Postal Service can design both the AMRs and the pilot in a way that minimizes possible operational limitations.

The OIG fully agrees that the technology itself is not currently mature enough for full-scale deployment and that the total cost and regulatory framework remain unclear. However, if current trends continue, these issues will be addressed in the coming years. In order to be ready for that future, the OIG advises making efforts to test real-world use cases in the short term.

Appendices

Click on the appendix title below to navigate to the section content.

Appendix A: AMR Technology

Sensors

Every AMR has sensors. They allow robots to "see" a picture of their environment and move around within it. Without them, autonomous robots would bump into something every few feet. AMRs that operate indoors generally use a more basic sensor array than their outdoor counterparts. There are fewer new objects to encounter indoors, and the distances that a sensor needs to see are much shorter. Moving objects rarely travel faster than 3 or 4 miles per hour indoors, unlike on the street where there are bicyclists and, in crosswalks, oncoming cars.

Most AMRs are equipped with a combination of different sensors, with each type having different advantages and disadvantages. In most cases, different sensors equipped to a single AMR have overlapping ranges and are capable of detecting the same obstacles in an environment, creating redundancy in the system. This redundancy allows more data about the environment to be collected, creating a more complete picture of what the robot is "seeing." Redundancy is an important measure for preventing AMR malfunction in the event of an individual sensor failure.
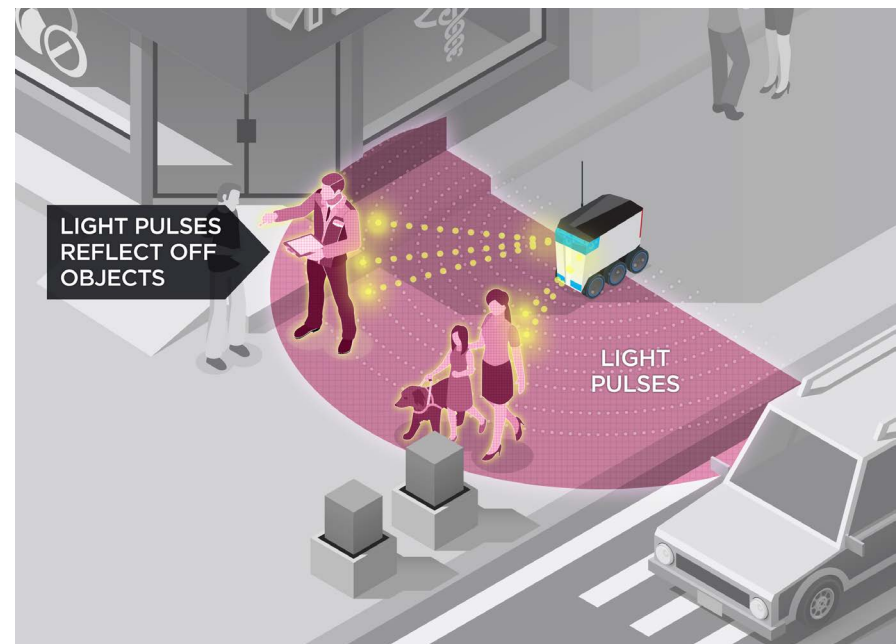
Lidar

Lidar, an acronym for Light Detection and Ranging, fires off pulses of light in many directions. By measuring how long the light beams take to bounce off a surface and back to the sensor, it can detect how far away the AMR is from objects around it. Since lidar sensors emit their own light, they can operate independent of ambient lighting, and many believe it is the most precise localization tool available. However, lidar does have a number of limitations. Bad weather, particularly fog and rain, can interfere with light pulses and cause the sensors to detect obstacles that are not there.[97] Additionally, lidar cannot identify objects which means it does not help an AMR determine how to navigate around or interact with a particular object or obstacle.

While perhaps the most precise sensor available, the cost of lidar presents an obstacle for AMR use. Currently, costs of high resolution 3-dimensional lidar sensors can cost upwards of $8,000, making the technology unattractive for AMR

use.[98] However, companies have demonstrated that high resolution lidar, while seemingly a must for high speed situations faced by autonomous vehicles, is not necessary for AMRs that travel in pedestrian environments. Rather, companies have successfully reached safe and competitive levels of autonomy without using high end lidar sensors.

Therefore, a number of companies, such as Robby and Unsupervised.ai, have integrated lower-resolution 2-dimensional and 1-dimensional lidar sensors that often cost less than $1,000. Although lidar use in robots is common, it is far from necessary. Some companies, such as Starship, have elected to not use lidar at all and have found other ways to build redundancy into their units.

Figure 6: How Lidar Sees

LIGHT PULSES REFLECT OFF OBJECTS

LIGHT PULSES

Source: OIG.

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97   Danny Bradbury, "How Autonomous Vehicles Will Navigate Bad Weather Remains Foggy," *Forbes,* November 29, 2016, https://www.forbes.com/sites/centurylink/2016/11/29/how-autonomous-vehicles-will-navigate-bad-weather-remains-foggy/#5731ec866298.

98   The price of lidar equipment significantly increases the cost of many AMRs. Many of the experts interviewed are anticipating the price of lidar equipment to drop significantly in the near future. A Ph.D. candidate at Massachusetts Institute of Technology (MIT), in discussion with the authors, November 6, 2017.

Radar/Ultrasonic Sensors

Radio Detection and Ranging, or radar, functions similarly to lidar. However, rather than emitting pulses of light, radar discharges radio waves. These radio waves bounce off nearby objects and return to the sensor, illuminating more distant objects as far as 200 yards.[99] Ultrasonic sensors function in a similar way by emitting a sound wave and using the distance measurements for short range object detection within a few feet.

Figure 7 : How Radar Sees
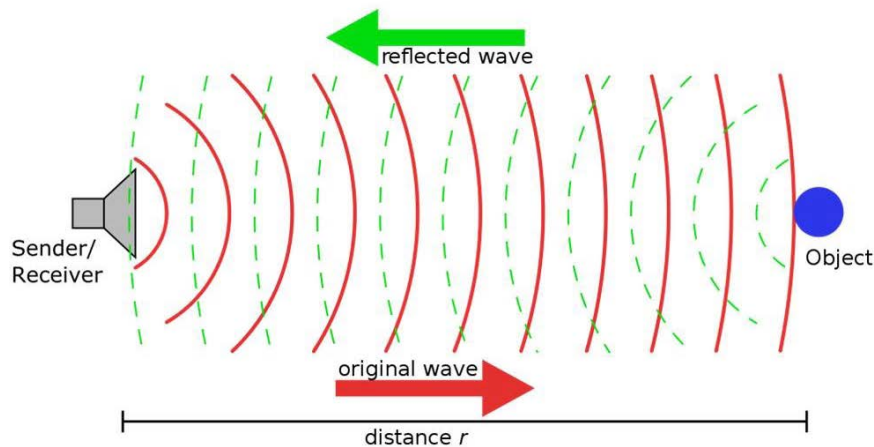
Source: Public Commons.

Radar has been around for a lot longer than lidar and, as such, is one of the more mature and tested types of sensors on the market. Like lidar, these sensors do not need ambient light to function but can only be used for detection purposes – they do not identify objects.

Companies that incorporate radar and ultrasonic sensors believe that the sensors can provide sufficient alternatives to more expensive lidar systems. Radar sensors cost less than $150 while ultrasonic sensors can be purchased for as little as 15 dollars.[100] However, the differences between high resolution lidar and its less expensive alternatives highlight the current tradeoff between precision and cost when dealing with such echolocation-like sensors.

Cameras

Cameras are arguably the most important sensor used by AMRs. Cameras are critical for the practice of computer vision – "the automatic extraction, analysis, and understanding of useful information from a single image or a sequence of images."[101] Using cameras, an AMR can detect and identify objects in its path. Cameras can be programmed to recognize objects and, for example, instruct AMRs to go around a signpost but let a dog pass by. Camera-based computer vision is perceived as advantageous due to its ability to identify objects at comparatively low cost. Cameras used for computer vision often cost less than $100 compared to other sensors which can cost thousands of dollars.[102]

However, computer vision has limitations as well. Cameras need to be programmed to identify objects. In a world with an infinite number of objects, cameras are ultimately limited in the number of objects it can identify. Additionally, cameras have a difficult time with depth perception, and can fail in low light or high glare situations.[103] Thus, while cameras are an important component for localization, they cannot safely navigate an AMR without the help of other sensor equipment.

99   Starship, 2017.
100 Alex Davies, "Turns Out the Hardware in Self-Driving Cars is Pretty Cheap," *Wired,* April 22, 2015, https://www.wired.com/2015/04/cost-of-sensors-autonomous-cars/.
101 British Machine Vision Association and Society for Pattern Recognition, "What is Computer Vision?," http://www.bmva.org/visionoverview.
102 MIT, 2017.
103 In 2016 cameras on an autonomous Tesla vehicle failed to identify a tractor-trailer against a bright sky resulting in a collision. Tom Simonite, "Self-Driving Cars' Spinning-Laser Problem," *MIT Technology Review*, March 20, 2017, https://www.technologyreview.com/s/603885/autonomous-cars-lidar-sensors/.

Figure 8: Computer Vision Software Identifies Other Vehicles on the Road
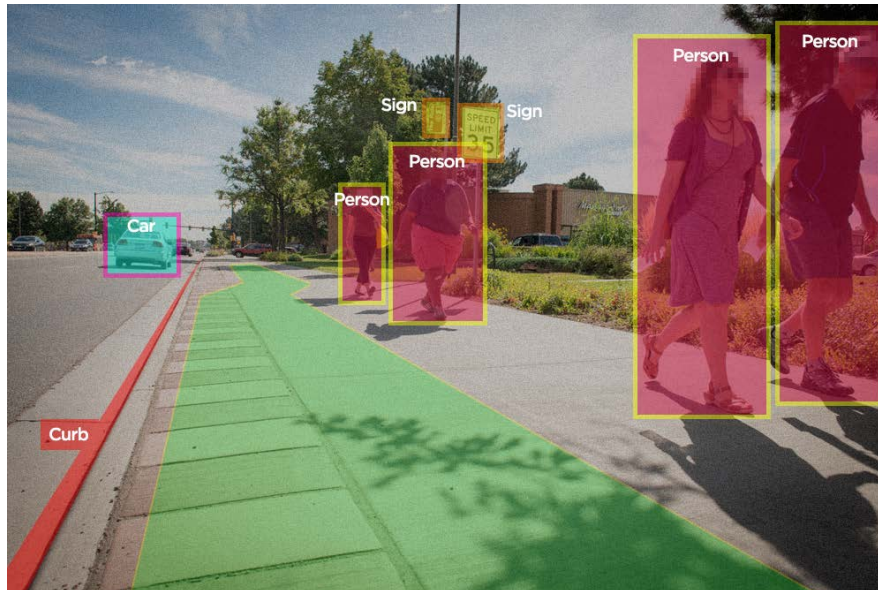
Source: OIG.

Fleet Management Software

In April 2017, Chinese media outlet People's Daily released a video showing dozens of orange robots, each the size of a seat cushion, buzzing around each other in a sorting center.[104] One look at this chaotically coordinated swarm makes it clear that the robots are operating not as individuals but as a collective. That kind of coordination is enabled by fleet management software that can perform increasingly sophisticated oversight of task execution. The software has a number of roles, including:

- Enforcing traffic rules (for example by determining right-of-way privileges when two AMRs approach an intersection);

- Deciding which AMR gets assigned to which job (by taking into account proximity and availability);

- Sending robots to charging stations when they are low on power; and

- Executing guidance parameters (such as the location of workstations where the robot should stop).[105]

In the case of the swarming orange bots at the Shentong Express sorting center, the entire system is controlled by a software "brain" that moves the robots around like fast-moving chess pieces, deciding which should go where and making sure they do not collide. A version of this is what powers rack-lifting robots such as those by Amazon Robotics or GreyOrange. These robots scan barcodes on the floor every few meters to alert the master computer where they are and receive instructions on where to go next.[106] Signals are sent via wi-fi, meaning that constant connectivity is a must.

Going a step further, robotics company Vecna's software is enabling its robots to be mission-based.[107] That is, rather than having a warehouse employee summon an autonomous pallet truck to a staging area, load a pallet onto it, and enter its destination manually, Vecna's system includes a set of instructions that empowers its pallet trucks to complete the mission without employee involvement. The robot, seeing that a pallet has arrived, can pick it up and bring it to a pre-assigned destination. If that destination is full, it can find its way to a second destination for drop-off.[108]

Mapping and Navigation

Arguably one of the most important advances in AMRs since the days of the Guide-O-Matic has come in mapping. The Guide-O-Matic, for example, followed

104 Sarah Zheng, "Chinese Firm Halves Worker Costs by Hiring Army of Robots to Sort Out 200,000 Packages a Day," *South China Morning Post,* April 11, 2017, http://www.scmp.com/news/china/society/article/2086662/chinese-firm-cuts-costs-hiring-army-robots-sort-out-200000.
105 A partnership manager at GreyOrange, in discussion with the authors, November 9, 2017.
106 GreyOrange, 2017.
107 Sparks, 2017.
108 Vecna, 2017.

a fixed route having no knowledge of its location in space. These guided vehicles have traditionally followed a track or magnetic strip along on the floor. Today, even the simplest AMRs are constantly localizing – a process in which AMRs map their surrounding environment and determine their presence within it. Nowadays, different AMRs use a number of localization methods, each ranging in levels of complexity.

Laser Guidance

For AMRs that use laser guidance localization systems, reflectors are affixed to walls or pillars around a facility in known and stable positions. An AMR operating within the facility emits a laser beam that bounces off the installed reflectors. The AMR can then use the reflected laser to triangulate its position. This localization methodology oftentimes provides a relatively low amount of information to the AMRs for mapping. Additionally, laser guidance mapping requires infrastructure adjustments, which could be difficult to implement in the Postal Service's existing facilities.

Teach and Repeat Method

"Teach and repeat" is a more complex localization method relative to common laser guidance practices. In teach and repeat, a person manually steers an AMR from Point A to point B on each of its work paths. Its sensors map the environment in real time and remember where in that environment the AMR is supposed to be. It can then drive those routes on its own by using its vision sensors to stay on track. With standard teach and repeat methods, an AMR's obstacle avoidance capability is limited. In the event of an obstacle, an AMR relying on teach and repeat mapping may not know to move outside its designated path to bypass the obstacle.[109]

Dynamic Path Planning

The most advanced navigation method is known as dynamic path planning. It begins with a person manually steering the AMR around a facility, but unlike with teach and repeat, the robot maps the entire facility, not just specific pathways.

People then mark the digital map with pertinent information: which objects are fixed, which are temporary, where the workstations at which the robot should stop are, and so forth. From then on, if the map has been sufficiently labelled, the AMR can move freely around the facility, choosing the most efficient path between any two points. If one path is blocked, it can choose another.[110] Only one robot needs to do the mapping, regardless of mapping technique used - maps can be shared across an entire connected fleet.

Outdoor Robots

Outdoor AMRs, on the other hand, cannot use wires, magnets, or lasers for navigation. Some companies choose to map the surrounding environment as they make deliveries, gradually creating full digital pictures of a city. These robots can share their mapping information with the fleet. Thus, the maps used by a robot can improve as the fleet grows and conducts more deliveries. However, manually mapping every block of every city in which they plan to operate is extremely time-intensive. In the future, robots may be able to rely exclusively on GPS to find their destination while their sensors handle obstacle avoidance.

Obstacle Avoidance

Unless they use dynamic path planning, most indoor robots cannot avoid obstacles in their path. The best they can do is slow down as they approach and stop once they reach it. Some will alert employees to the situation by making a noise or sending a message, but in the end they need a human to remove the obstruction before they can continue on.[111] A few indoor AMRs can divert slightly from their route to go around the obstacle, if they determine the obstacle is stationary.

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109 For example, Seegrid robots at the Postal Service's Pennwood sorting center were incapable of moving around even small objects and terminated movement until the object was manually cleared from its path.
110 Oxbotica, 2017.
111 Senior executives and an account manager at Seegrid, in discussion with the authors, April 4, 2017.

Video 7: MIT's Socially Aware Motion Planning Robot
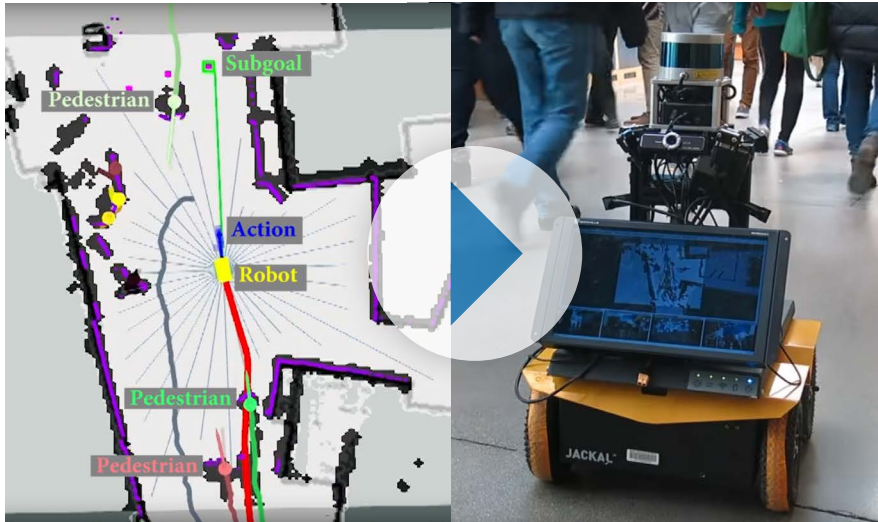
Source: MIT Aerospace Controls Lab.

Delivery robots must be able to go around obstacles or they will not make it down a single block. Trees, benches, signposts, telephone poles, trash, and uneven concrete are just some of the impediments on a typical sidewalk. Their software identifies what each object is and instructs the robot how to behave. If it is safe, they go around fixed objects. For moving objects, they usually stop and wait for it to get out of the way. If a person in their way is not moving, some AMRs play a voice message that says "excuse me" and "thank you." Researchers at MIT are using machine learning to train AMRs to follow human social norms when moving through crowds.[112]

New Features

One troublesome obstacle that delivery robots cannot drive around is stairs. Some can climb curbs, but stairs remain a problem. Since many homes and businesses have at least a few stairs, customers must meet the robot on the sidewalk. One solution is to replace a robot's wheels with special treads that are able to climb stairs; Transcend Robotics makes a $2,000 base with stairclimbing treads that can attach to the body of a robot.[113] Another solution is building an AMR that walks rather than rolls. Aida, a four-legged robot from the company Unsupervised.ai, will begin pilots in 2018 with an unnamed delivery company.[114]

Many companies are adding other helpful features to their delivery robots. Notable examples include:

- Wirelessly calling a building's elevator to be able to travel between levels in any given facility,[115]

- Customer verification through facial recognition, and[116]

- Understanding voice commands and gestures.[117]

Developments continue to be made in all these areas, and the pace of development appears to be increasing as there is more and more interest in using mobile robots for delivery and in logistics. However, the technology is still not ready for full rollout – there are glitches that prevent seamless use, and the more advanced capabilities like dynamic path planning and machine learning are still being developed, tested, and perfected. Nevertheless, the potential for these AMRs is becoming quite evident and will continue to grow as these shortcomings are addressed.

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112 Machine learning leverages artificial intelligence and allows programs to automatically learn and improve from previous experience without requiring reprogramming. MIT, 2017.
113 Transcend, 2017.
114 Unsupervised.ai, 2017.
115 Savioke, 2017."
116 JD.com, 2017
117 Roston, 2017.

Appendix B: Postal Service Pilots with AMRs

To date, the Postal Service has not completed any pilots of robots for last mile delivery, although they do monitor the technology from afar. The Postal Service does, however, have a decades-long history of AMR pilots in sorting centers. This appendix presents information about these pilots that the OIG gathered from interviews with postal personnel.

Past Efforts

Pre-2000s

As far back as 1984, the Postal Service tested transporting mail through carts that traveled autonomously along wires placed into grooves in the floor. However, these pilots ended because the wires frequently broke and the vehicles stopped often, delaying the mail.[118] In the late 1990s, at a test bed facility in Fort Myers, Florida, the Postal Service used laser-guided tuggers and forklifts (where a rotating laser on top looked for reflective icons around the facility) manufactured by AGV Products to transport mail from docks to stations. The Postal Service also partnered with Carnegie Mellon University in 1992 to develop a concept of automated "spotters" – tractor-trailers meant to transport mail at Bulk Mail Centers.

Brooklyn

The first major pilot, according to OIG interviews with postal personnel, occurred in the early 2000s at the processing and distribution center (P&DC) in Brooklyn, New York. The Postal Service purchased 10 robotic tuggers from AGV Products, and for a period of about 10 years, these AMRs moved trays of mail from sorting machines to docks.[119] Two types of guidance were used, both requiring infrastructure additions: a magnet guidance system on the floor and a laser guidance system (where a rotating laser on top looked for reflective icons around the facility).

Despite the relative simplicity of the technology, the Postal Service observed some major benefits. The time it took to move flats to docks was cut from 10 hours to under four hours, which allowed the Postal Service to cut PIV operator overtime by 80 or 90 percent. The pilot program remained functional for over 10 years. The Postal Service even proposed upgrading the pilot with new machines, but this pilot was eventually discontinued.[120]

Current Efforts

Pennwood Place Tuggers

In 2016, the Postal Service started using four autonomous tuggers manufactured by Seegrid to move mail to and from loading docks and between machines at the Pennwood Place P&DC outside Pittsburgh.[121] The pilot began with four AMRs but has since expanded to eight. Employees summon the tuggers through tablets mounted at key points around the facility, near stations where the AMRs stop. Employees hitch carts to the AMRs, which can pull up to five carts along the trained routes. At the time of our interview with postal employees at Pennwood, the AMRs had been trained on 22 routes.

Although these AMRs can move on their own, they stop behind obstacles, blocking aisles and creating traffic jams.[122] Their travel areas have to always be kept clear. Additionally, the robots return to a "taxi stand" after each task, meaning a robot cannot build a queue of tasks. As a result, it cannot provide an estimated arrival time to the employee who called for it unless it is leaving directly from the taxi stand. Despite these limitations, employees seem to like the robots. In fact, when wi-fi problems caused the robots to briefly stop working, some employees expressed disappointment because they had come to rely on them.[123]

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118 Representatives of the National Postal Mail Handlers' Union (NPMHU), in discussion with the authors, December 4, 2017, and Maravas, 2017.
119 Vecna, 2017 and Maravas, 2017.
120 Maravas, 2017.
121 Sparks, 2017; Seegrid, 2017; Maravas, 2017 and NPMHU, 2017."
122 For safety reasons, the Seegrid tuggers move at a maximum speed of 2.5 mph and go much slower than that when turning. In comparison, PIV operators can drive 4.5 mph. This further slows the pace of mail movement. Bieranowski and Baker-Spanos, 2017.
123 Ibid.

Queens and Richmond - Pallet Movement

The Postal Service plans to set up a pilot in Queens in early 2018, with one in Richmond to follow not far behind.[124] At Queens, nine pallet jack AMRs manufactured by Daifuku will be rolled out in the three-story facility to move pallets of packages from a sorting machine to a pallet elevator. This highly repetitive task, where pallets are taken off one machine and brought to the same place over and over, is a prime candidate for automation. In Richmond, the Postal Service is looking to place eight pallet jacks and two tuggers, also by Daifuku, into the new facility.

The AMRs for these pilots will be guided by magnetic tape. The Postal Service reported that they wanted to test this type of guidance system not only as a matter of due diligence but also because such AMRs are well-developed and simple to use – the tape is easy to install and the guided vehicles do not require complicated software and design programs.

Capitol Heights – Pallet Movement

The Postal Service has purchased four AMRs produced by Grenzebach for pallet movement at the Network Distribution Center (NDC) in Capitol Heights, Maryland. While this sounds similar to the Queens and Richmond pilots, it is very different in style. The short, flat Grenzebach AMRs slide under specially-designed pallet racks and lift them up, rather than using a typical forklift mechanism. They will bring pallets from the dock to a person at the dumping machine that enters mail into the sorting system, then collect empty pallets for return to the staging area.

One of the complications with this style of "lifting" AMR is that they require their own brand of racks. At a cost of only $60,000-$70,000 per robot, their price is much more attractive than some of the autonomous heavy machinery, which runs about three times that amount. However, this lower price does not include the software and racks. Additionally, since they are smaller robots, they will likely not command as much aisle space as PIVs do, meaning they could become operational in more spaces.[125]

Figure 9: Grenzebach AMR for Capitol Heights Pilot

Source: Grenzebach.

Although the Postal Service reports having the robots in hand already, this pilot is not yet installed because the software solution and IT integration is not yet ready. As such, there are no results to report. However, it is encouraging that the Postal Service is considering this out-of-the-box method of pallet movement.[126]

Further Evaluation and Testing Moving Forward

In addition to the companies mentioned above, the Postal Service evaluated AMRs from the following suppliers: Adept, AGV Solutions, Clearpath, Dematic, JBT Corporation, Oceaneering, Transbotics, Vecna Technologies, MURATEC,

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124 Bouchard, 2017 and Sparks, 2017.
125 With dimensions of only about 1x4x2 feet, the Grenzebach is much smaller than a typical PIV (the Seegrid tugger is 3x8.5x5 feet), although both travel in autonomous mode at about 2.5 miles per hour. Sparks, 2017; Bouchard, 2017; and Seegrid Vision, "Vision Guided Vehicle: GT45 Tow Tractor," https://seegrid.com/wp-content/uploads/2016/09/gt45_product_spec_brochure.pdf.
126 Bouchard, 2017.

Meiden, DS Automation, Kollmorgen Corporation, Bastian Solutions, Solystic, and Hyster-Yale.

The Postal Service is in the process of acquiring and testing models from four of those suppliers for further evaluation.[127] In addition to the specific planned pilots described above, the Postal Service is hoping to roll out AMRs to 25 yet-to-be-identified processing plants by the end of 2018.[128] Some of these new companies may be tested at those sites.

Key Findings

- A one-for-one replacement of employees with robots is not expected. There are going to be tasks that are better suited for people, and tasks that are better suited for robots (particularly those that are repetitive). The Postal Service recognizes that robots cannot just be dropped in a facility and expected to work without a plan, and that plan requires human intelligence and high-level planning.[129]

- Engagement with the union has been important.[130] Employee buy-in is necessary, especially since plant management has a say in the pilots that take place in their facility. As a result, the Postal Service has worked to educate employees about the technology and work closely with those in the field.[131]

- The Pennwood, Queens, and Richmond pilots represent a limited view of automation. These tuggers and pallet jacks are manual machines with AMR technology added. This allows someone to get on and manually drive it if need be, and parts are more readily available. However, it does not represent a rethinking of how to change the process entirely.[132] The proposed Capitol Heights project would be a first step in this direction.

- The Network Operations group, reporting to the Chief Operating Officer, has until recently managed postal AMR pilots. In August 2017, responsibility for these pilots shifted to the Engineering group, reporting to the Chief Information Officer. While there is some coordination between the groups on current and future projects, it is unclear how much past lessons learned are informing current efforts.[133]

- The Pennwood, Queens, and Richmond sites feature wide aisles, a requirement for PIV AMRs. The Postal Service currently requires 10 to 12-foot aisles for AMR deployment; only about 30 of the 258 plants could accommodate them at present. However, sorting machines can be rearranged – if these AMRs demonstrate sufficient return on investment, the Postal Service could reconfigure plants so that more could take advantage of the technology.[134] Regardless of the aisle width, aisles will need to be kept clear so that AMRs can pass through.[135]

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127 Sparks, 2017.
128 Ibid, and Bieranowski and Baker-Spanos, 2017.
129 Sparks, 2017 and Bouchard, 2017.
130 Sparks, 2017.
131 Maravas, 2017; Bouchard, 2017; and Sparks, 2017.
132 Having a driver seat is not a prerequisite for manual operation – many AMRs are controlled remotely through a mobile app or specific remote controller. Bouchard, 2017 and Maravas, 2017.
133 Maravas, 2017. The OIG picked up bits and pieces through different interviews, often hearing conflicting details.
134 Sparks, 2017 and Maravas, 2017.
135 The requirement for such wide aisles comes from the Postal Service's safety department. The 10-foot requirement is for one-way AMR traffic, plus space for pedestrians to walk safely. For two-way traffic, you need at least 12-foot aisles. This is based on the width of the machines themselves, plus the clearance they need for turning. Maravas, 2017.

Appendix C: Pilots at International Posts

Currently, a handful of international posts are testing AMR technology in both delivery and sorting centers. This appendix presents information the OIG gathered about pilots from posts in Estonia, Australia, Switzerland, Germany, and Portugal through interviews and press releases.

Estonia – Omniva

From July until October 2017, Omniva, Estonia's post, tested AMRs for last-mile delivery.[136] Using robots from fellow Estonian company Starship Technologies, the pilot took place in a 10-km-wide section of Estonia's capital city, Tallinn. Omniva intended to gauge public opinion, increase their brand awareness, and determine the company's overall preparedness for implementing an AMR delivery fleet.

During the pilot, Omniva worked with Mercedes Benz to test out the Robovan concept – a van that carried eight robots and 54 packages. An Omniva courier drove the Robovan along a route, stopping at designated release points to put packages in the robots and release them for final delivery. Upon completion of the delivery, the robots would go to designated dropoff points to be picked up by the Robovan. Starship handled the software and coordination elements of the pilot, in addition to training the couriers.

Customers were sent a hyperlink via SMS message to a page where they could choose their delivery time.[137] They received follow-up reminder messages one hour before the expected delivery and again when their order arrived.

Feedback was largely positive. Omniva reports that 91 percent of customers that responded to a customer satisfaction survey liked the service and indicated that they would choose to receive packages from a robot again. Additionally, there was a novelty factor, in which customers stopped the robots to take pictures with them (which ended up slowing down deliveries considerably).

In total, Omniva delivered 1,166 parcels through the Robovan pilot. The company praised the pilot's lack of operational disruption, as well as the positive press and customer response. However, because the robots were not autonomous enough to handle crosswalks and sidewalk construction without intervention from human operators in all cases, deliveries cost more than with regular human carriers.[138]

Australia – Australia Post

Since 2016, Australia Post's innovation team has managed its own accelerator, providing seed funding, mentorship, and pilot opportunities for startups working on ecommerce business solutions.[139] In October 2017 as part of its accelerator, Australia Post announced a 4-week "proof of concept" pilot with Sydney-based Marathon Robotics. During the trial, Australia Post deployed Marathon's 220 pound, single compartment autonomous delivery robot to the streets of New Farm, a residential neighborhood of Australia's third largest city, Brisbane.

As part of the proof of concept pilot, the robot provided nighttime re-delivery for customers missing a first daytime delivery attempt. During the pilot, select customers were sent an SMS message offering mobile robot re-delivery between 6 p.m. and midnight. Those interested in re-delivery were then asked to provide their preferred delivery window. Within the preferred window, customers that opted in would then receive an SMS message stating the robot was on its way. Upon the robot's arrival, customers received a final arrival notification. Customers then completed the delivery by meeting the robot outside and replying to the SMS message to unlock the robot's compartment to collect the package.

In total, Australia Post conducted over 100 mobile robot re-deliveries during its 4 week pilot. Customer satisfaction was overwhelmingly positive. One hundred percent of customers said they would use the re-delivery service again, while nine out of 10 said they would recommend the service to a friend. Three out of four customers said they would pay a premium for the robot-enabled nighttime delivery service.

Although customer satisfaction surrounding the pilot proved promising, Australia Post also validated a number of operational considerations that limit the cost

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136 Omniva, 2017.
137 Omniva found that their customers most preferred a one hour delivery window. Additionally, customers reported that they preferred delivery window accuracy over faster delivery times.
138 Most of the time, though, the deliveries were made without a person accompanying the robot. Argos, 2017.
139 Australia Post, 2017.

effectiveness of robot delivery today. Regulations required delivery robots to constantly operate within the line of sight of a human handler during the pilot. For this trial, to operate safely, Australia Post required the human handler to approve the autonomous crossing of roads at intersections. At the same time, Australia Post observed that a single-compartment robot needing to return to a fulfillment center and re-stock after each delivery was inefficient and un-scalable.

Nevertheless, Australia Post believes that many of the cost effectiveness obstacles are temporary roadblocks rather than permanent limitations. The post believes autonomy levels will continue to improve, allowing a single remote operator to monitor an increasingly large delivery fleet. Likewise, they are optimistic that regulations will ease and eventually remove the human handler requirement, enabling fully autonomous delivery. Moving forward, the post plans to explore options to conduct multiple deliveries prior to returning to a fulfillment center for restocking. Ultimately, Australia Post believes that robot-driven nighttime delivery could become commercially viable in under 5 years.

Switzerland – Swiss Post

Swiss Post has been running delivery pilots since September 2016 with Starship robots.[140] It was partnering with department store Jelmoli to offer free robot-based delivery to customers in the downtown Zurich area. After a customer chooses the AMR option, a Swiss Post handler, working out of a room at the Jelmoli store, loads the package and programs the address into the robot.[141] Swiss Post was also delivering contact lenses to customers in Dubendorf on behalf of online retailer discountlens. Swiss Post completed the tests at the end of January. The main purpose of the pilot series was to determine whether and to what extent the delivery robots are suitable for use in the last mile delivery of goods.

In total, Swiss Post has fulfilled more than 570 direct-from-store deliveries. Because of their slow speed and battery limitations, the robots only make about one delivery per hour in a 3 km radius. Per Swiss regulations, a Swiss Post employee must accompany the robot at all times in their pilots so far, which means the cost of delivery is currently high. The post has also been working with startup TeleRetail for further feasibility testing of delivery robots.

Germany – Deutsche Post DHL

DPDHL is known for being on the cutting edge of new technologies. It believes AMRs will allow it to process increasing parcel volumes while maintaining current workforce levels.[142] To this end, it sponsors a robotics accelerator and a robotics challenge to engage with suppliers for different use cases.[143]

In contrast to Swiss Post and Omniva, DHL has focused on robots that work collaboratively with employees in both warehouses and delivery. It believes labor-augmenting robots will help resolve employee shortages and retention issues while keeping workers' councils and customers happy. DHL is finding that these solutions can achieve returns on investment in less than three years, a timeframe it expects to decrease as AMR technology becomes less expensive.

In its warehouses, DHL is working with a number of robotics companies to automate picking, packing, tugging, and pallet movement. For example, DHL tested a pilot in 2003 with a container unloading robot, the Parcel Robot. However, DHL never adopted the Parcel Robot concept as the pilot showed the technology was "insufficiently mature to implement."[144] Two years ago, DHL started to test a collaborative robot with arms from Rethink Robotics, named Baxter, that performs packing and assembling tasks. While DHL found Baxter cannot yet handle all common packing tasks, DHL has already purchased a dozen of Rethink's second generation packing robots, named Sawyer.[145]

140 Swiss Post, 2017 and Matt McFarland, "Switzerland Enlists Robots to help Deliver Mail," CNN, August 24, 2016, http://money.cnn.com/2016/08/24/technology/switzerland-swiss-post-ground-robot/index.html.
141 The retailer donates space in the store to Swiss Post for the post to store the robots until they are used. Using a post office would not be operationally ideal since valuable time and battery charge would be wasted by first having to drive to the retailer for the delivery to be loaded.
142 DHL, November 2017.
143 "Accelerator programs are programs of limited duration that help cohorts of startups with the new venture process." https://www.mitpressjournals.org/doi/abs/10.1162/INOV_a_00184.
144 DHL, *Robotics in Logistics*, March 2016. http://www.dhl.com/content/dam/downloads/g0/about_us/logistics_insights/dhl_trendreport_robotics.pdf.
145 DHL, "DHL Invests in Four New Collaborative Robots to Provide a Flexible and Innovative Solution for its UKI Co-packing Customers," May 5, 2017, http://www.dhl.com/en/press/releases/releases_2017/all/logistics/dhl_invests_in_four_new_collaborative_robots_to_provide_a_flexible_and_innovative_solution.html.

For delivery, DHL debuted the PostBOT, another Effidence creation, in the German city of Bad Hersfeld in October 2017.[146] Capable of carrying over 300 pounds of mail and parcels, the eye-catching yellow PostBOT follows mail carriers along their delivery routes, handling the entire physical burden. Carriers now only need to carry packages the last few feet of delivery, reducing stress and injury. Thus far PostBOT has only delivered to addresses near its post office base of operations, so the carrier can walk with it out the front door and onto the route. DHL has not yet had it ride in vehicles to locations farther away.

Portugal – CTT Portugal Post

Recently, CTT Portugal Post has focused on consolidating its sorting centers.[147] CTT has adopted automated processes that have increased throughput and enables the post to sort all of Portugal's mail from two locations. Engineers introduced a fleet of pallet-tugging AMRs to transport heavy boxes of unsorted packets to a stationary robotic arm that feeds the boxes onto conveyer belts for sorting. CTT has now deployed three such AMRs, each costing less than $25,000, in a test pilot. Upon receiving instructions from a centrally-managed system, the AMRs identify and collect the specified pallet. The robotic arm then unloads the six to eight boxes stacked on top of the pallet onto the conveyer belt for sorting. Afterwards, the AMR returns the empty pallet to its storage location and retrieves another full pallet. They repeat this process until all of the pallets are empty.

According to one pilot manager, the AMRs have become "an essential part" of their operation. Operators that previously worked on the now-automated tasks have been transferred to other operations. Moving forward, CTT believes that its AMRs will be able to perform a number of additional sorting center functions. The post does not imagine using robots for last-mile delivery in the short- or medium-run, however.

Key Observations

- So far, posts have predominantly conducted pilots with AMRs that assist employees, or are at least accompanied by them. Crosswalks and unforeseen obstacles such as construction are substantial obstacles for fully autonomous delivery.

- Public and employee perception of the AMR pilots has been largely positive, according to the posts. Omniva and Swiss Post found their last-mile AMR pilots delivered positive press and brand notoriety, and customers enjoyed the experience. Employees are encouraged by AMRs that assist employees rather than replace them.

- Most of the pilots have not yet achieved a desirable return on investment. Delivery pilots actually produced a negative ROI, for two reasons. First, the posts did not charge customers an extra fee for this premium service. Second, robots had to be partially controlled by remote operators and were often accompanied by human chaperones. The salary costs of those employees made the deliveries expensive.

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146 DHL, "New Delivery Robot Helps Mail Carriers Make Their Rounds," October 4, 2017, http://www.dpdhl.com/en/media_relations/press_releases/2017/new_delivery_robot_supports_mailmen.html.
147 CTT Portugal Post, 2017.

Appendix D: Regulations Covering Delivery Robots

As mentioned in the paper, no federal laws exist in the U.S. regarding the operation of delivery robots on public sidewalks. However, a number of state and local municipalities have created legislation conditionally permitting delivery robot operation. The first table below summarizes key points of existing regulations from a sample of major metropolitan areas. The second table summarizes existing regulations for each of the five states that have passed legislation as of January 9, 2018.

Regulations at the Local Level

Locality	Date Enacted	Testing-only Restriction	Speed Limit (mph)	Weight Limit (lbs)	Details
Redwood City, CA[148]	11/13/2016	Yes	10	80	Requires commercial general liability insurance ($4,000,000), bodily/personal injury insurance ($2,000,000), property damage liability insurance ($1,000,000 per accident), plus automobile and workers comp insurance.
Washington, DC (Current)[149]	10/8/2016	Yes	10	50	In case of technology failure, robot must be retrieved by owner within 24 hours.
Washington, DC[150]	(Proposed)	No	10	90	$1,000,000 public liability and property damage insurance required; $1,000 permit fee per applicant.
Austin, TX[151]	8/10/2017	Yes	10	300	$1,000,000 general liability insurance.
Concord, CA[152]	10/3/2017	Yes	10	500	$4,000,000 bodily injury, personal injury, and property damage insurance $1,000,000 automobile liability required. This was specifically a pilot run by the company Marble. Starship also has a pilot (approved in July 2017).
San Francisco, CA[153]	12/5/2017	Yes	3	None	General, automotive, and workman's comp insurance (unspecified amounts); No more than 3 robots per permit holder. Human operator must be within 30 ft.

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148 Redwood City, "Conditions of Approval for Personal Delivery Device 'PDD' Use Permit," November 13, 2017, http://www.redwoodcity.org/home/showdocument?id=13110.
149 Fiscal Year 2017 Budget Support Act of 2016, D.C. Law 21-160, https://code.dccouncil.us/dc/council/laws/21-160.html.
150 DDOT, 2017.
151 Austin City Council, "Personal Delivery Devices Draft Resolution," July 20, 2017, http://www.austintexas.gov/edims/document.cfm?id=282589.
152 For draft text see: Concord City Council, "Regular Meeting of the Concord City Council," October 3, 2017, http://www.cityofconcord.org/pdf/citygov/agendas/council/2017/1003/6A.pdf.
153 San Francisco Board of Supervisors, "Revised Legislative Digest," December 5, 2017, Draft Text, https://sfgov.legistar.com/View.ashx?M=F&ID=5675962&GUID=C23EBA7F-DF09-472B-A644-6E97400676B9. Vote Passage: http://sanfrancisco.granicus.com/MediaPlayer.php?view_id=10&clip_id=29322.

Regulations at the State Level

State	Date Enacted	Speed Limit (mph)	Weight Limit (lbs)	Details
Virginia[154]	2/24/2017	10	50	Municipalities can prohibit but not further regulate delivery robots.
Idaho[155]	3/24/2017	10	80	Municipalities may adopt further regulations for the safe operation of delivery robots on sidewalks.
Florida[156]	6/23/2017	10	80	Municipalities may adopt further regulations for the safe operation of delivery robots on sidewalks; $100,000 commercial general liability insurance requirement.
Wisconsin[157]	6/21/2017	10	80	Municipalities can prohibit but not further regulate delivery robots.
Ohio[158]	6/30/2017 (effective 9/29/2017)	10	90	Municipalities may enact additional regulations that apply to the operation of delivery robots; $100,000 general liability insurance requirement.

154 Virginia Legislature, "Electronic Personal Delivery Devices; Operation on Sidewalks and Shared-use Paths," SB 1207, 2017, https://lis.virginia.gov/cgi-bin/legp604.exe?171+sum+SB1207.
155 Idaho Legislature, "Personal Delivery Devices," HB 204, 2017, https://legislature.idaho.gov/sessioninfo/2017/legislation/h0204/.
156 Florida Legislature, "Unmanned Devices," HB 1027, 2017, http://www.flsenate.gov/Session/Bill/2017/1027.
157 Wisconsin Legislature, "2017 Wisconsin Act 13," SB 148, 2017, https://docs.legis.wisconsin.gov/2017/related/acts/13.
158 Ohio Legislature, "Creates FY 2018-2019 Operating Budget," HB 49, 2017, https://legiscan.com/OH/text/HB49/2017.

Appendix E: List of Interviews

Company	Interview Date
Association for Advancing Automation	11/20/17
Australia Post	1/26/17
AutoGuide Mobile Robots	11/2/17
AutoStore	11/17/17
Carnegie Mellon University, National Robotics Engineering Center	10/26/17
CTT Portugal Post	12/18/17
District Department of Transportation	11/7/17
DHL	11/28/17
Duke University Humans and Autonomy Lab	2/21/17
Effidence	11/9/17
GreyOrange	11/9/17
IAM Robotics	11/1/17
JD Logistics	12/4/17
Knapp Inc.	11/16/17

Company	Interview Date
Marble	10/10/17
Massachusetts Institute of Technology	11/6/17
National Postal Mail Handlers Union	12/4/17
Occupational Safety and Health Administration	11/30/17
Omniva	12/12/17
Otto Motors (Clearpath Robotics)	11/20/17
Oxbotica	11/7/17
Piaggio Fast Forward	11/15/17
Postmates	11/29/17
Robby Technologies	11/8/17
RoboCV	4/7/17
Robotic Industries Association	11/29/17
San Francisco Board of Supervisors	1/16/17
Savioke	10/31/17
Seegrid	4/4/17

Company	Interview Date
Segway Robotics	11/15/17
SRI International	11/17/17
Starship	12/4/17
Swiss Post	12/11/17
Swiss Post	3/30/17
Swisslog	11/1/17
TeleRetail	11/2/17
Tompkins Robotics	11/2/17
Transcend Robotics	11/16/17
Tusk Holdings	11/27/17
Twinswheel	11/14/17
Unsupervised.ai	11/13/17
U.S. Postal Service	9/11/17
U.S. Postal Service	12/11/17
U.S. Postal Service	12/12/17

Company	Interview Date
U.S. Postal Service (Site Visit)	10/25/17
U.S. Postal Service (Site Visit)	10/2/17
U.S. Postal Service	12/8/17
U.S. Postal Service	12/7/17
Vecna	11/20/17

Appendix F: Management's Comments

KEVIN L. MCADAMS
VICE PRESIDENT, DELIVERY OPERATIONS

UNITED STATES POSTAL SERVICE

March 30, 2018

AMANDA MARTINEZ
MANAGER, RARC CENTRAL
RISK ANALYSIS RESEARCH CENTER

SUBJECT: Autonomous Mobile Robots and the Postal Service
Report No. RARC-WP-XX-XXX

Postal Service Headquarters has reviewed the findings and recommendations outlined in the Office of Inspector General (OIG) Autonomous Mobile Robots (AMRs) and the Postal Service. Overall, we agree with some of the findings and disagree with some that pertain to piloting AMRs in delivery. The following are specific OIG comments and our contentions:

OIG report: Delivery Application: The Postal Service has been more hesitant to try delivery robots, since the business models and return on investment (ROI) are not yet proven and the technology needs to further mature to better face the challenges of moving in outdoor spaces. But OIG research suggests that there are use cases for delivery robots the Postal Service could start testing today. Below are potential applications for AMRs in delivery, both for:

•Accompanied delivery, where robots transporting mail and packages would follow carriers to help them complete their job faster with less physical effort;

•Independent delivery, where robots would deliver packages to recipients directly and on their own, without a carrier accompanying them.

USPS Comments on Accompanied Delivery: The bulk of the fleet used for delivery are not designed to accommodate a 400lb AMR and do not have an integrated ramp that would allow the AMR to roll out of the back of the vehicle. The cubic space required for the AMRs (PostBOT 4ft x 2.25ft x 5ft) would also quickly utilize the 121 cubic feet of cargo space in our Long Life Vehicle (LLV)/Flex Fuel Vehicle (FFV) delivery vehicles which would limit room for the actual mail being carried for the individual route. The current PostBOT model is too tall to actually fit in the back of an LLV/FFV. The fleet would need to be aligned to accommodate these AMRs for motorized routes.

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Data is not included in the report to indicate the time spent by a carrier to load or unload the AMR into the vehicle and the time spent loading the AMR with mail and retrieving it. It would be anticipated that the number of relay and park points should be significantly reduced if an AMR was utilized to offset this time, but the savings needs to be significant to provide an ROI.

There is potential to test a follow-the-carrier AMR on a foot route as it would eliminate the complications with capacity and ramps required for our fleet.

Curbs, stairs, uneven pavement, weather, inattentive pedestrians and landscape would still cause multiple issues. At points the carrier would be required to back track to pick up the AMR at the obstruction and prevent the carrier from taking all of the obvious shortcuts between delivery points.

USPS Comments on Autonomous Delivery from Post Offices: The technology for autonomous delivery is still immature and still requires human intervention to make decisions for anomalies that occur during the trip and when crossing streets. The range of delivery is very small, typically less than a mile from the launch point, and the demand for the service is limited. Currently a human chaperone is required to accompany the autonomous delivery robots which also limit their effectiveness.

As mentioned in the report the cost is very high for autonomous delivery robots and it is highly unlikely that it will ever be cheaper than a mail carrier, due to the slow speed of delivery, ability to only delivery one package at a time, and the small fraction of the population that could be served each day. The option to lease the robots from a company that specializes in this field is interesting but the small customer base that could utilize this option would have to be willing to pay the premium for the per delivery or subscription cost for this service.

USPS Additional Comments and Concerns: Current regulations are limited to a small number of states and are likely to be created when or if delivery robots become widely utilized. These regulations may add additional costs to a small market making the ability to see an ROI improbable. Those states that due have regulations require a high liability insurance which will also be a burden on a self-insured company like the Postal Service. Although there have only been a hand full of accidents involving autonomous robots, as seen from the most recent incident with an autonomous vehicle, they can be extremely harmful to the brand.

The potential to improve the carrier's work environment through AMRs by reducing the time and distance that a heavy package or bundle of mail would need to be carried is interesting, but this would need to be studied more carefully over time to determine if the data supports this theory.

All of the current tests on last mile delivery by AMRs presented in the report show that the cost and technology are not yet mature enough for real application in the last mile market.

The Postal Service is very interested in this technology and will continue to track and monitor the progress being made along with the public perception and regulations governing this technology. The current Deutsche Post pilot will be a good indicator if the follow-the-carrier AMRs have potential for a near future test in the Postal Service.

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UNITED STATES POSTAL SERVICE

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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).