COWEN

Collaborative Insights
Robotics

AHEAD OF THE CURVE® SERIES

DEUS EX MACHINA, PART II

NOVEMBER 14, 2019

Warehouse/logistics robotics is a younger, more dynamic market than traditional robotics and expected to grow from ~$4B today to over $22B by 2022.

Through our partnership with MassRobotics, we conducted a proprietary survey of market participants and developed an industry growth model that supports third-party estimates.

Robotics is a fragmented, largely private, and North-American-centric landscape: private investment in 2019 of ~$8B is over 9x 2014 levels. Giants like AMZN historical consolidators.

Labor trends within the sector have improved considerably despite rapid acceleration in robotic deployment. Anti-globalization trends likely foster US development and leadership.

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In Collaboration With
massrobotics

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COLLABORATIVE INSIGHTS

November 14, 2019

- Process Control & Automation

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INDUSTRY OVERVIEW

DEUS EX MACHINA, PART II - AHEAD OF THE CURVE SERIES

THE COWEN INSIGHT

Part II of a collaborative, multi-part series examining the global robotics landscape (see Part I HERE). Firmly entrenched trends in how people choose to purchase goods (towards eCommerce), increasingly nationalistic trade policies, and challenging labor dynamics support continued investment into a developing, US led innovation market. Part II focuses on warehouse/logistics robotics.

Our Proprietary Market Models And Survey Results Suggest A Rapidly Growing Opportunity - Continued End-User Education Likely To Accelerate Demand – Joe Giordano

Since 2000, US retail sales have roughly doubled to over $6T and eCommerce sales have increased over 2000% to nearly 10% of total (from <1%). To support the shift in customer behavior, we've seen a tripling of the workforce in US warehouses vs. a gross change of <15% for total employment over the same period. Warehouse wages have grown at ~2x the overall US pace over the past 3 years after underperforming over the past 20 in order to draw in more labor. As eCommerce growth continues and the workforce is stretched - job openings in the space outpace hirings by the most in 20 years - robotics will need to fill the void.

World Robotics estimates that the logistics robot market will expand rapidly from ~$2.5B in 2017 to over $22B globally by 2022. We partnered with MassRobotics to develop a model to estimate the minimum spend required to support just US eCommerce growth, and see that market as nearly $8B in 2024. When we consider that US eCommerce sales are only 10% of total retail sales and that US retail is only ~25% of the global total - the overall market is clearly much larger. We also partnered with AMZN analyst John Blackledge to create an AMZN based robotics model given they are the market leader via their 2012 acquisition of Kiva. Our analysis there supports our other market estimates - and suggests a $7+B US market in 2022.

Our proprietary survey of ~20 robot manufacturers / end users (conducted by Cowen and MassRobotics) identified an interesting hurdle to current adoption that likely fades near-term. Nearly 25% of robot manufacturers believe adoption is negatively impacted by skepticism over reliability, whereas only 5% of robot users identified this as an issue. Users cite high capex costs to deploy and maintain as the primary obstacle (nearly 30%) though the most common payback cited was generally 2 years or less. With advances in sensing and mapping technologies allowing for more seamless robotic deployments (without the use of predetermined routes and tracks) and lower cost (estimated annual price declines of ~200bps on average), these results suggest continued exposure will ultimately accelerate implementation.

The US Stands As The Innovation And Supply Engine For Warehouse/Logistics Robotics; See Potentially Robust Landscape Of Emerging (Mostly Private - For Now) Players

Whereas traditional robotic arms are largely supplied by European and Japanese giants, warehouse / logistics robotics development is centered in the US (with Boston as a primary hub). World Robotics estimates that over 90% of the ~111,000 logistics robot systems supplied in 2018 (~$4B estimated value) came from the US. The landscape for these types of robotics is largely private, and as such we've seen investment scale materially over the past several years. PitchBook data suggests private investment in robotics has ballooned from just over $800MM in 2014 to ~$8B already this year - with ~50% of cumulative investment towards North America based businesses. Logistics related investment (ex drones) represents the largest subsector, with ~$3B invested this year (and a nearly 100% 5-year CAGR from 2014-2019).

The market remains highly fragmented, with leaders often swallowed by major users like Amazon (which acquired Kiva for $775MM in 2012) and Shopify (which recently announced a $450MM acquisition of 6 River Systems). Such transactions create market voids, as the purchasers have historically monopolized the acquired technology, creating opportunities for new leaders to emerge. World Robotics identifies nearly 50 "major" producers of logistics robots alone, and this excludes mobile robots in manufacturing applications. It will be interesting to see how the structure of this market evolves - will smaller private companies scale and become material suppliers or will the current trend of scooping up technology to use internally at big players continue?

Robotics: New Potential Front in US-China Tech Wars – Chris Krueger, Cowen Washington Research Group

The bipartisan U.S.-China tech war continues to move through the Made in China 2025 industries of the future via methodical use of the Entity List, industrial policy and likely further export controls; robotics is a key industry of Made in China 2025 and we expect a future flashpoint in the broader tech war. While accelerated under Trump, the broader idea that globalization has been a net loser for the U.S. and that it needs to be replaced with greater regionalization holds significant bipartisan staying power. As the theory goes, there are inherently lots of countries and trading blocs (China first and foremost, but also the Europeans and Japan) who do not play fair with trade. The U.S. goal should be to discourage supply chain linkages with these countries and regions and ideally re-source to the U.S. and our North American neighbors. Canada and Mexico serve as natural pieces of a regional marketplace.

There is broad U.S. government consensus that the Chinese government is attempting to do to high-value manufacturing (the critical industries of the future identified in the Made in China 2025 initiative) what they did to low-value manufacturing over the past 30+ years, i.e. dominate. China's targeted industrial policy will be matched by U.S. industrial policy and national champion policy. In May 2015, the Chinese State Council released their unbelievably high-level industrial policy -- Made in China 2025 -- to effectively dominate ten sectors of the emerging economy: 1) next-generation information technology; **2) high-end numerical control machinery and robotics;** 3) aerospace and aviation equipment; 4) marine engineering equipment and high-tech maritime vessel manufacturing; 5) advanced rail equipment; 6) energy-saving and new energy vehicles; 7) electrical equipment; 8) new materials; 9) biomedicine and high-performance medical devices, and; 10) agricultural machinery and equipment. 5G is the current sectoral battleground for the broader U.S.-China decoupling, though over the coming years we fully expect similar clashes within all of these sectors – with Entity List designations as the tip of the spear. We continue to detect a widespread, bipartisan, durable shift in the U.S.-China relationship. The former "Kissinger Consensus" has been jettisoned between the December 2017 National Security Strategy and the October 4, 2018 speech from Vice President Pence, which were defining statements of intent: the U.S.-China relationship is no longer cooperative and commercial, but confrontational and competitive.

Amazon's Robotics Initiatives Essential To Meeting Growing eCommerce Demand Long Term – John Blackledge

Amazon is the leading US eCommerce platform with 35% market share. We estimate Amazon's US units sales will rise from 6.3B in '19 to 11.0B units by '24. To address this demand AMZN has built a US fulfillment network that spans 149MM square feet and ramped headcount considerably. Additionally, Amazon has continued investing in robotics technology to increase efficiency. Amazon acquired Kiva Systems in 2012 and since the acquisition, has engaged >200K robotic drive units in their fulfillment facilities, creating a step function in inventory capacity and increasing safety. Amazon has continued to iterate on the Kiva technology since the purchase, rolling out the latest models earlier this year, and has also developed technology that will help people and machines work in closer proximity, further increasing productivity. The evolution of Amazon's robotics efforts have likely helped the company shift to Prime 1 Day delivery.

Executive Summary – Joe Giordano

Part II of our robotics series dives into the fast-growing warehouse/logistics market (see Part I, focused on traditional industrial robotics, HERE), which World Robotics expects to expand from ~$4B today to over $22B by 2022. We leveraged our recent partnership with MassRobotics – a leading, non-profit hub for robotics startups – to carry out a proprietary survey of robotics users and manufacturers and develop a market model for demand based on eCommerce trends that support World Robotics' growth algorithm. We also collaborated internally, with Amazon analyst John Blackledge, to develop an Amazon-based robotics demand model and explore strategies the market leader is taking to address demand, and with Washington Research policy expert Chris Krueger to look at how US/China relations could impact market development longer term.

Unlike traditional robotics, which have been around since the 1960s, warehouse/logistics robotics are much earlier in their deployment journey. More recent advances in sensing, mapping, and IIoT technology have made this type of investment more reasonable, and continuing shifts in consumer behavior towards eCommerce is stressing the labor force available to meet demand. These trends essentially ensure market development for robotics technologies, as humans alone will not be sufficient to ensure global fulfillment of goods. Our survey shows good alignment in terms of applications desired by users and currently being developed by manufacturers (pick and place and product movement/handling/delivery), and over 90% of manufacturer respondents either already have a commercially available product or will in less than a year. As the robots themselves become more commonplace, the ability to deploy quickly, minimize downtime, interface with other technologies, and seamlessly integrate with broader warehouse management systems likely determines winners in the space.

Investor interest in the broader startup robotics space remains high and is accelerating, though there is a noticeable lack of publicly traded options, at least currently. There is a robust, US-centric private market, however, with 7 companies having raised over $750MM in cumulative capital and 3 (nearly 4) over $1B. The mobile robot space in particular has seen 6 companies raise at or above $500MM with two high profile exits (Amazon's $775MM purchase of Kiva in 2012 and Shopify's recent $450MM acquisition of 6 River Systems).

As we did in Part I, we examined how a trend towards increased robotics adoption in the warehouse/logistics space has and is impacting the job market. Once again, the "robots are taking our jobs" argument simply fails to hold water. Warehouse employment has tripled since 2000 despite exponential growth of robotic deployments (albeit off a low base) and current job openings stand at the highest level over the period. As a percentage of total employment, the warehouse/transportation sector has effectively doubled. Wages are growing well in excess of the national average as employers seek to entice applicants – all signs of a healthy and expanding market despite continued deployment of new robotics technology. Given rising tensions with global trade partners, robotics end users in the US are incentivized to support the domestic landscape rather than rely on foreign technology – in this regard we believe the current lead held by the US is important and one that will need to be maintained and fostered.

The US landscape for this next wave of robotics development is robust and one that will be defined over the years to come. There will be failures, no doubt, but there will be many successful outcomes and we believe an overall buoyancy to the market as this type of technology will essentially be a requirement to handle the needs of an increasingly demanding consumer.

Key Investment Considerations For PMs:

1. Growth is early stage and poised to ramp considerably – our eCommerce and Amazon based models support IFR's growth algorithm towards a $20+B market. (link)
2. The US is the center of innovation for this phase of robotic development and private investment dollars are ramping considerably (~$8B so far this year) into a fragmented landscape. (link)
3. Historical precedent of forward-looking companies acquiring robotics leaders, utilizing tech internally, and creating market voids. (link)
4. Our survey suggests a meaningful near-term product introduction cycle, good manufacturer/user alignment, but disparity on cost/value proposition. (link)
5. Robotics taking jobs in this sector is an absolute fallacy – data shows a vibrant and tight warehouse labor market despite robotics deployment. (link)

In July 2019, Cowen and MassRobotics announced a partnership to bring together their extensive market knowledge in the areas of emerging robotics and artificial intelligence. This collaborative report is one outcome of our combined efforts.

Figure 1 Warehouse/Logistics Robotics Overview – Automated Guided Vehicles (AGVs) To Drive Growth

Global Logistics Robotics Estimated Annual $ Value
(in $ '000)

	2017	2018	2019E	2020E	2021E	2022E
AGVs (non-manufacturing indoor)	$1,914,123	$3,142,416	$4,984,040	$7,929,024	$12,649,335	$20,242,864
AGVs (manufacturing)	$478,315	$504,338	$719,944	$961,574	$1,346,014	$1,921,900
All Other Logistic Robots	$3,819	$12,603	$23,078	$44,626	$101,857	$286,708
Total Logistics Robot Value	**$2,396,257**	**$3,659,357**	**$5,727,062**	**$8,935,224**	**$14,097,206**	**$22,451,472**
y/y growth		*52.7%*	*56.5%*	*56.0%*	*57.8%*	*59.3%*

Total Robotics Private Investment Dollars, 2014-2019

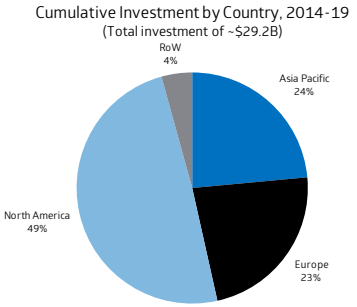
	2014	2015	2016	2017	2018	2019 (YTD)
AGVs / AMRs / Service Robots	$97.9	$411.9	$731.8	$1,328.6	$1,203.4	$2,971.6
AI / Machine Vision / Enabling Technologies	$190.5	$735.0	$444.6	$1,859.6	$1,730.4	$2,386.6
Industrial / Collaborative Robots	$53.6	$703.3	$789.8	$1,039.0	$3,611.2	$418.0
UAVs / Drones	$318.4	$553.2	$591.2	$784.7	$749.6	$874.3
Exoskeleton/Wearables	$35.5	$124.0	$14.3	$763.6	$99.8	$1,038.1
Consumer Robots	$135.3	$217.5	$301.2	$526.2	$1,143.5	$228.5
Total Investment	**$831.1**	**$2,744.9**	**$2,872.9**	**$6,301.6**	**$8,537.9**	**$7,917.1**

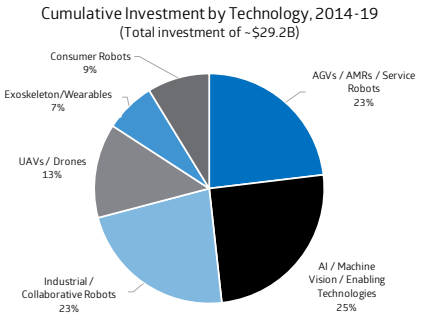
Major Robot Acquisitions by Public Companies

	Acquirer	Date	Price Paid	Technology
Cruise	GM	5/16/2016	$1000MM	Self-Driving Vehicles
Kiva Systems	Amazon	8/6/2012	$750MM	AMRs/AGVs
6 River Systems	Shopify	10/17/2019	$450MM	AMRs/AGVs
Endeavor Robotics	FLIR	3/4/2019	$387MM	AGVs/Defense Robotics
Universal Robots	Teradyne	6/11/2015	$350MM	Collaborative/Industrial Robots
Blue River Technologies	Deere	10/12/2017	$305MM	Agriculture/AGVs/Machine Vision
Liquid Robotics	Boeing	12/9/2016	$300MM	Underwater AMRs
Mobile Industrial Robots (MiR)	Teradyne	4/25/2018	$273MM	AMRs/AGVs
Adept Technologies	Omron	10/23/2015	$200MM	AMRs/AGVs
AutoGuide Mobile Robots	Teradyne	10/21/2019	$165MM	AMRs/AGVs
Robopolis	iRobot	10/2/2017	$141MM	Consumer Robots

Key Private Mobile Robot Companies (Private Co)

	Investor	Last Investment	Post-Valuation	Technology
Nuro	Softbank, Banyan Capital & Greylock Partners.	2/11/2019	$2700MM	AMRs/AGVs
Starship Technologies	Morpheus Ventures, TDK Ventures, QU Ventures, Shasta Ventures & others.	8/20/2019	$100MM-$500MM (estimated)	AMRs/AGVs
Fetch Robotics	Fort Ross Ventures, Softbank, Zebra Ventures, Redwood Technologies & others.	7/23/2019	$221MM	AMRs/AGVs
Locus Robotics	Zebra Ventures, Scale Venture Partners & others.	4/11/2019	$184MM	AMRs/AGVs
Right Hand Robotics	Menlo Ventures, GV, Playground Global & others.	12/17/2018	$88MM	Picking Solutions
Veo Robotics	GV, Baidu Ventures & others.	1/1/2019	$70MM	Enabling Technology
Savioke	Swisslog, Xplorer Capital, Brain Corp & others.	9/13/2018	$67MM	AMRs/AGVs
Simbe Robotics	Venrock, Cherubic Ventures, SOSV, Presence Capital & others.	9/12/2019	$60MM	AMRs/AGVs
Soft Robotics	Yamaha Motor Ventures, Laboratory Silicon Valley & others.	4/1/2019	$50MM	Picking Solutions
Vecna Robotics	Tectonic Ventures, Drive Capital & others.	8/28/2018	$45MM	AMRs/AGVs
Marble Robot	Tencent, Gelt Venture Capital, Fox Ventures & others.	1/18/2018	$38MM	AMRs/AGVs





Source: IFR – World Robotics 2019, PitchBook, Company reports, Cowen and Company

Warehouse / Logistics Robotics Poised For Rapid Growth – eCommerce A Key Underlying Driver

Investment Consideration #1: Growth is early stage and poised to ramp considerably – our eCommerce and Amazon based models support IFR's growth algorithm towards a $20+B market.

The International Federation of Robotics (IFR, interchangeable with World Robotics in this report) expects demand for warehouse / logistics related robotics to expand from <$4B annually today to over $22B by 2022, primarily through proliferation of Automated Guided Vehicles (AGV) and its more advanced subgroup, Autonomous Mobile Robots (AMR) – see our Primer HERE for additional technical detail.

Figure 2 Global Logistics Robotics Demand Expected To Expand To $22+B By 2022

Global Logistics Robotics Estimated Annual $ Value
(in $ '000)

	2017	2018	2019E	2020E	2021E	2022E
AGVs (non-manufacturing indoor)	$1,914,123	$3,142,416	$4,984,040	$7,929,024	$12,649,335	$20,242,864
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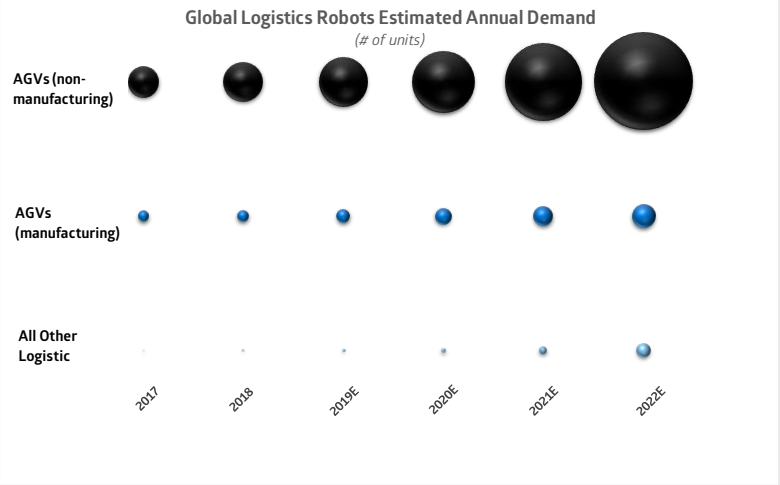


Source: IFR – World Robotics 2019, Cowen and Company

Underpinning the expansion are two critical and ultimately related trends: **1)** changing consumer behavior and **2)** labor challenges. Each of these factors is supplemented by incrementally harsher anti-globalization policies at national levels in key markets.

Today's consumer is increasingly dictating not only what they want, but how, where and when they want their products. Consumers have become more demanding - they want locally produced, highly personalized, and low-cost products, delivered the same-day or with free-shipping and return optionality. Speed is no longer a competitive advantage, it is a requirement that consumers have come to expect. With eCommerce continuing to become a larger chunk of US (and global) retail sales logistics, fulfillment and warehouses must evolve and become more efficient in order to meet growing demand. With this in mind, we developed two warehouse/logistics market models based on eCommerce trends and Amazon's robotic deployment to support IFR's growth assumptions.

Some 20-years ago, Jeff Bezos built Amazon around the principal of what wouldn't change in terms of consumer habits: "*You can build a business strategy around the things that are stable in time. In our retail business, we know that customers want low*

prices, and I know that's going to be true 10 years from now. They want fast delivery; they want vast selection. It's impossible to imagine a future 10 years from now where a customer comes up and says, "Jeff I love Amazon, I just wish the prices were a little higher." Or, "I love Amazon, I just wish you'd deliver a little slower." Impossible."

Today's consumer has forced companies to make significant investments in both human capital and enabling technologies that help them meet these new demands. It is essentially impossible to achieve things like 1-day delivery without the help of automation and robotics – both of which help increase throughput and shorten delivery times.

When we look at all the steps involved to fulfill an order, it becomes clear that many of these stages can be automated by robots to speed the process and reduce costs.

Figure 3 Various Steps That Make Up The Fulfillment Process Can Potentially Be Automated

Source: Honeywell Intelligrated, Cowen and Company

The "Amazon Effect" is prevalent in the world of mobile robots – when Amazon purchased robot maker Kiva Systems in 2012, a void was created within the autonomous robot space and dozens of robot start-ups were born as a consequence. Retailers, logistics companies and 3PLs have all been forced to employ higher levels of automation, AGVs and AMRs in order to provide the speed, flexibility and low-cost, quick delivery that Amazon established, while at the same time battling challenging labor conditions.

See HERE for additional detail on the robot/labor dynamic

According to Logistics Management's 2018 Distribution Center Survey, the inability to attract and retain a qualified hourly workforce was the leading industry issue and was cited by 55% of respondents (a 6% increase from the 2017 survey). Moreover, the survey was completed before Amazon announced that it would make $15/hour its minimum wage for U.S. employees starting in November 2018, which likely brings the labor crunch issue even more top of mind for logistics/warehouse employers.

The labor challenge is twofold. First there is a significant manual labor requirement in a warehouse and meaningful time is wasted as a result. Consider the fact that about half of the human labor in warehouse is doing simple and arduous tasks and employees often *walk a dozen miles per day* as part of their job. Conceivably, some of these tasks

could at the very least be augmented by robots, thereby reducing time spent and increasing efficiency. In many of these tasks, robots can do the same job as a human at 3-5x speed, with clear productivity benefits. There is a significant labor shortage within warehouses, particularly around peak holiday season when tens of thousands of workers are hired every year to help fulfill increased delivery demands. Warehouse work also ranks among the riskiest of jobs with an accident rate over 50% higher than the overall average according to the U.S. Bureau of Labor Statistics – robots can help make warehouses safer while improving efficiency.

Don Derewecki, senior consultant with St. Onge Company (supply chain engineering consulting firm) said that growing volumes, difficulties finding labor, and more piece picking as part of e-commerce are driving increased use of automation. Mr. Derewecki also acknowledged that automation is necessary to help meet complex customer requirements under tight time lines.

Cowen's US eCommerce Based Warehouse/Logistics Robotics Model

We worked with MassRobotics and its partner network to develop a model for warehouse/logistics robotics demand based on US eCommerce trends. We consider this to be an indicator of a minimum level of robotic investment as it only seeks to capture the spending needed to sustain eCommerce growth after exhausting realistic growth of the human labor force. This would NOT capture opportunistic investment by forward thinking companies looking to gain a competitive advantage or by traditional retail companies seeking to evolve their business model (like WMT is currently doing). Our work suggests a nearly $8B market by 2024 just related to US eCommerce – when we consider that eCommerce is only ~10% of total US retail sales and that US sales are only 25% of the global total – it implies a total market at least in line – if not larger – than the $20+B estimate from the IFR.

Quick walkthrough of our methodology

Since 2000, US eCommerce sales have expanded over 20x to nearly $600B – moving from <1% of total retail sales to ~10%. Over that same period, spending on warehouse related labor has more than tripled from ~$15B (or nearly 60% of eCommerce sales) to over $45B (<10% of eCommerce sales).

Figure 4 eCommerce Growth Up >20x Vs. 2000 And Moving Towards ~10% Y/Y Growth

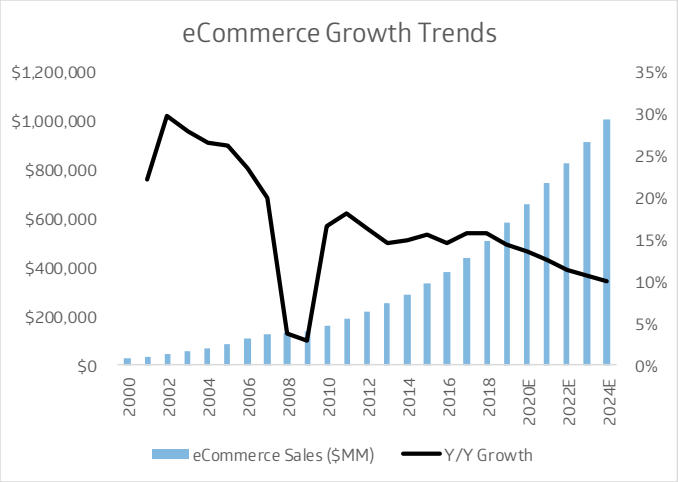
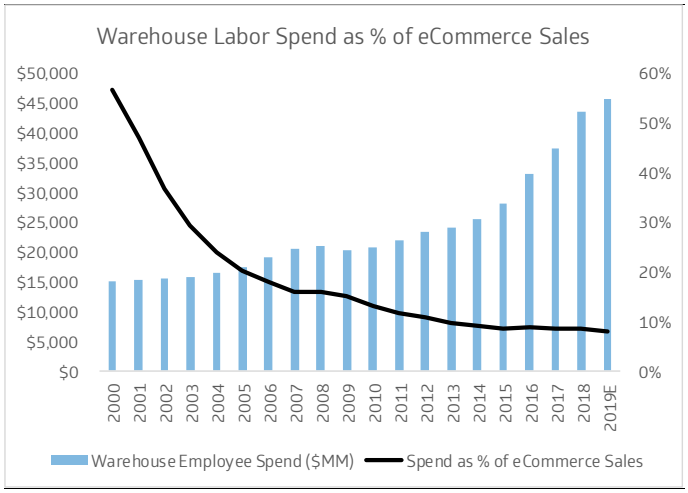


Figure 5 Associated Warehouse Spend Ramped With eCommerce And Normalizing Towards ~8% Of Total eCommerce Sales



Source: Bureau of Labor Statistics, US Census Bureau, Cowen and Company

eCommerce growth is expected to decelerate towards a ~10% growth rate by 2024 and we've seen warehouse spend as a % of eCommerce sales (essentially the labor infrastructure required to support a given level of sales activity) normalize at ~8% of sales. We consider this spending level to be the amount of "work" needed to satisfy a given level of eCommerce activity. Given low robotics penetration today, much of that "work" is satisfied by human labor.

For the purposes of our model, we assume that the required investment to support eCommerce growth as a % of sales remains at the ~8% level seen the past several years. Part of that annual required cost will be met through human labor – and we assume warehouse hiring growth continues at 6% a year and wages expand 3.5% annually – both well above national averages and in line to higher than what is currently happening in the sector today. The difference between the 8% total spend required to support eCommerce and our calculated human component essentially represents the minimum robotics investment required to meet eCommerce demand.

Figure 6 US eCommerce Based Warehouse/Logistics Demand Model – See Nearly $8B Minimum Requirement In 2024 From US eCommerce Alone

	A		B	C = A x B	D					E = C - D	
					Human Component						
	Estimated US eCommerce Sales ($MM)	Y/Y Growth	Estimated Investment Required to Support eCommerce (% of eCommerce Sales)	Estimated Investment Required to Support eCommerce ($MM)	Warehouse Employees ('000)	Y/Y Growth	Wages	Y/Y Growth	Total Labor Investment ($MM)*	Implied Minimum Robotic Spend ($MM)	Y/Y Growth
2019	$581,746	14.4%	8%	$46,540	1,188	4.3%	$18.50	3.7%	$45,492	**$1,047**	
2020	$660,497	13.5%	8%	$52,840	1,260	6.0%	$19.14	3.5%	$50,160	**$2,679**	156%
2021	$742,971	12.5%	8%	$59,438	1,335	6.0%	$19.81	3.5%	$55,031	**$4,407**	64%
2022	$827,532	11.4%	8%	$66,203	1,415	6.0%	$20.51	3.5%	$60,375	**$5,828**	32%
2023	$915,038	10.6%	8%	$73,203	1,500	6.0%	$21.22	3.5%	$66,237	**$6,966**	20%
2024	$1,005,588	9.9%	8%	$80,447	1,590	6.0%	$21.97	3.5%	$72,669	**$7,778**	12%

*Total Labor Investment assumes a 40 hour work week and 52 weeks a year.

Source: US Census Bureau, MassRobotics, Cowen and Company

Cowen's US Warehouse/Logistics Robotics Model Based On Amazon Deployments

We partnered with Cowen's Internet research team, led by John Blackledge, to approximate the US logistics/warehouse robotics market size using Amazon as a proxy, given the company's extensive deployments and utilization of robots in recent years and its 25-35% share of US eCommerce (depending on how you define Amazon's sales). We consider our finding to be representative of a minimum level of robotics spending required to fulfill estimated eCommerce spending outside of estimated headcount growth within logistics/fulfillment operations. Our estimate does not factor in additional investment from 3PLs, retailers, logistics providers, and other competitors looking to catch up to Amazon's significant robot utilization and deployments (we saw Shopify acquire 6 River Systems for $450MM in September 2019, which looks very similar to Amazon's acquisition of Kiva Systems in 2012). Our work suggests a $7+B market by 2024 (5-year CAGR of ~25%), which supports our market size approximation with MassRobotics – and implies a total market at least in line with the $20+B global estimate from IFR.

Figure 7 USA Logistics/eCommerce Robot Market Size 2019-24E

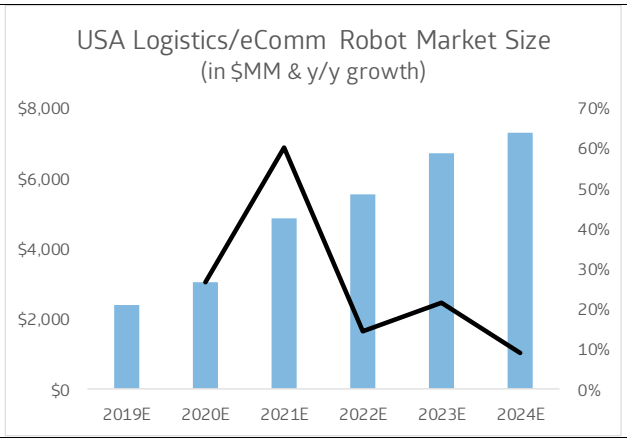
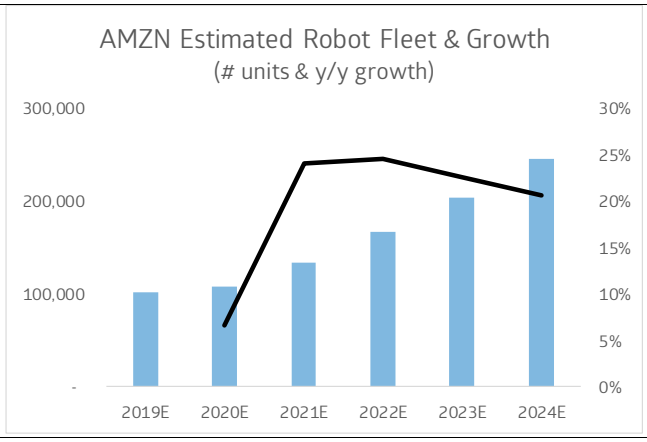


Figure 8 AMZN's Estimated Robot Fleet At Year End, 2019-24E



Source: Cowen and Company, Amazon Robotics, World Robotics, MassRobotics

Quick walkthrough of our methodology

Through its purchase of Kiva Systems in 2012, Amazon become the earliest adopter of robotics at scale for logistics purposes - setting a precedent for both retail/eCommerce competitors and logistics companies. At the re:MARS conference in June 2019, Amazon Robotics VP Brad Porter said the company has deployed 100k robots in U.S. operations (>200k globally) to support its ~125k U.S. based fulfillment employees.

We arrive at our U.S. market size by first approximating how many robots we believe Amazon will have to deploy in order to meet Cowen's estimated U.S. Gross Merchandise Value (GMV) - the gross value of merchandise that is moved through Amazon's fulfillment centers. U.S. GMV is the best figure to use for estimating Amazon's share of total US eCommerce spend.

Within our model we assume fulfillment headcount growth will be in line with Cowen's estimate for total Amazon headcount growth until 2023 when we assume the pace of hiring will slow to 8% and 7% in 2023 and 2024, respectively. This growth rate is above the national average, but given minimum wage increases at Amazon and other hiring initiatives, we view this assumption as reasonable. For AMZN to meet our estimated

U.S. GMV, there will be a mix of employees and robots working together to move products through the fulfillment process. Given we have already accounted for yearly headcount growth, the additional "labor" needed to fulfill U.S. GMV will need to come from robot purchases. We also give Amazon credit for productivity increases each year based on robot density (robots per employee).

We take AMZN's estimated robot purchases and divide it by AMZN's % share of total U.S. eCommerce to arrive at U.S. unit demand. We then multiply this number by the estimated average cost per robot to arrive at yearly minimum spend on eCommerce logistics/warehouse robots.

Figure 9 Amazon Robotics Based Model For Logistics Robotics Demand – See ~$7.3B Minimum Requirement in 2024 From US eCommerce

	A		B					C	D = B / A	E = C / D		
			Amazon Components							Implied Market Size		
	Estimated US eCommerce Sales ($MM)	Y/Y Growth	AMZN U.S. GMV	Y/Y Growth	Headcount	Y/Y Growth	Robot Fleet*	Total Robot Purchases (*units*)**	Amazon as a % of US eCommerce	Implied Robot Demand USA (# units)	Implied Minimum Robotic Spend ($MM)	Y/Y Growth
2019E	$581,746		$146,939		125,000		100,000	17,000	25.3%	67,305	**$2,389**	
2020E	$660,497	*13.5%*	$172,941	*17.7%*	143,750	*15.0%*	101,000	22,657	26.2%	86,533	**$3,026**	*26.6%*
2021E	$742,971	*12.5%*	$200,195	*15.8%*	161,719	*12.5%*	107,657	37,931	26.9%	140,770	**$4,848**	*60.2%*
2022E	$827,532	*11.4%*	$226,586	*13.2%*	177,891	*10.0%*	133,588	44,694	27.4%	163,232	**$5,537**	*14.2%*
2023E	$915,038	*10.6%*	$252,736	*11.5%*	192,122	*8.0%*	166,282	55,540	27.6%	201,084	**$6,719**	*21.3%*
2024E	$1,005,588	*9.9%*	$280,732	*11.1%*	205,570	*7.0%*	203,822	62,006	27.9%	222,105	**$7,310**	*8.8%*

*Fleet at beginning of the year.

**Total Robot Purchases includes new robot purchases, replacement of stock at end of useful life, and an assumption for early replacement before end of life.

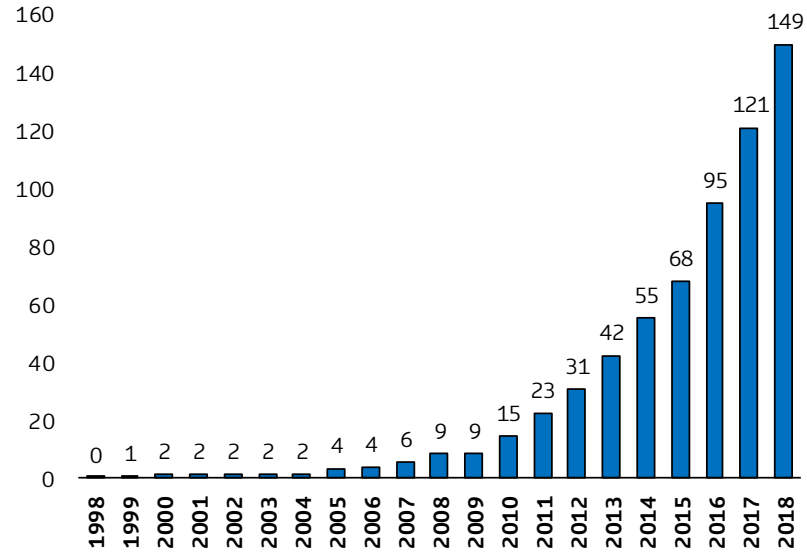
Source: Cowen and Company, Amazon, Amazon Robotics, World Robotics, MassRobotics.

Amazon Investing Significantly In Buildings, People And Robots To Meet LT Demand – John Blackledge

Amazon is the largest eCommerce retailer in the United States with 35% share of US eCommerce in '19 per our estimates. We believe that Amazon will be responsible for moving 6.3B units through its US fulfillment network in '19 and expect that number to rise to 11.0B units by '24, all while increasing shipping speeds as it continues to expand its Prime One Day shipping offering to an ever-increasing number of SKUs.

To address the growing demand Amazon has rapidly expanded its fulfillment square footage and headcount over the past several years. Based on data from MWPVL, Amazon's US fulfillment network ended 2018 with ~149MM square feet, up nearly 120% from 2015. Amazon ended 3Q19 with 750,000 employees, adding over 95K people in the quarter alone, with management noting that the primary driver of headcount growth was operations personnel related to the buildout of Prime One Day and the busy holiday shopping period. Headcount is up 22% y/y and up ~120% since the start of 2017. Headcount growth at this scale is not sustainable over the long term, in our view, and necessitates Amazon's continued investment in robotics technology to increase efficiency.

Figure 10 Estimated Square Footage Of Amazon's US Network '98-'18 (MM)



Source: Cowen and Company, MWPVL International.

Next Generation Of Amazon Robots Focused On Driving Fulfillment Efficiencies

To address its long-term fulfillment needs Amazon acquired Kiva Systems, a leader in the robotics industry, in 2012 for $775MM. Since that time Amazon has continued to iterate on its robotics technology. Since the Kiva acquisition, AMZN has engaged >200K robotic drive units in their fulfillment facilities, helping drive a step function in inventory capacity and increasing safety. When we attended Amazon's Re:MARS conference, which highlighted the company's work in AI, ML, Space and Robotics, in June we saw a showcase of the company's newly unveiled Pegasus and Xanthus robots (the spiritual successor to some of the Kiva robots), which provide greater flexibility and can handle more tasks than previous models. Beyond the Kiva robots themselves Amazon also highlighted the work it is doing to allow people and machines to work in closer proximity to increase efficiencies. These included vests that allow workers to safely move about the floor without disrupting the workflow of robots, which continue to speed from task to task, and carts that follow workers and assist in transporting tools and products throughout these facilities. Overall, we came away incrementally positive on the company's efforts to remain at the cutting edge of robotics technology following the conference and view Amazon as leader particularly among retailers in the robotics space.

Figure 11 Updated Warehouse Robots Increase FC/DC Efficiency

Source: Amazon.com Day One Blog

What Technologies Are Required To Accelerate/Incentivize Deployment And How Do Providers Establish An Advantage? -Joe Giordano

For more detail on key enabling technologies, see our Primer HERE

Mobile robots by nature require an incremental technology stack vs. traditional robotics. Early versions of warehouse robotics were highly rigid, moving in a non-collaborative way through a facility on a predetermined path without regard for things/people in their way. Advances in sensing technology (like LiDAR), mapping, and connectivity (IIoT, cloud) have allowed mobile robots to move more seamlessly, avoid obstacles, and integrate within broader warehouse IT and management systems.

These technologies simply opened the door for end-user adoption – and we are seeing that trend gain steam. However, longer-term the robots themselves will become more commoditized and the true value will reside in data management / facility efficiency. Companies that demonstrate the ability to deploy technologies quickly, minimize downtime, integrate effectively with other systems, and track progress to continuously optimize will be winners. We expect to see a trend towards robotics as a service (RaaS) models where ownership of the robot never transfers to the end-user. Instead of a large upfront capex cost, a periodic fee is paid for use of the system. It's a more stable stream for the manufacturer and is attractive to the end-user as it minimizes upfront cost and can fall more within an operating budget. We have already seen early evidence of similar shifts within broader industrial automation.

The US Is The Innovation Hub Of A Largely Private, Fragmented Landscape - And Investment Dollars Are Pouring In

Investment Consideration #2: The US is the center of innovation for this phase of robotics development and private investment dollars are ramping considerably (~$8B so far this year) into a fragmented landscape.

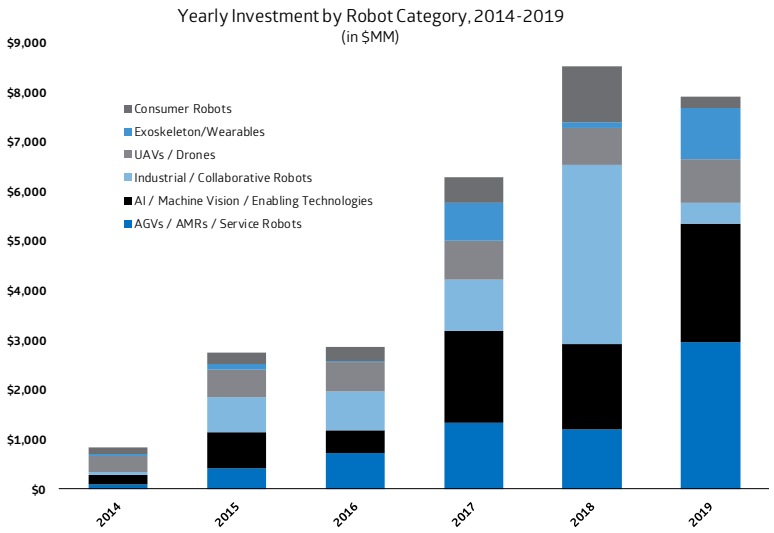
While the collaborative/mobile robotics industry continues to mature, it remains early stage. Most of the players remain private, and leaders that have emerged have, in many cases, been acquired by large companies looking to gain a competitive technology advantage (Amazon, Shopify, etc.). Appetite from private capital is clear, and we've seen annual investment dollars (based on PitchBook data) expand from <$1B to ~$8B over the past 5 years. The majority of investment was directed towards North America,

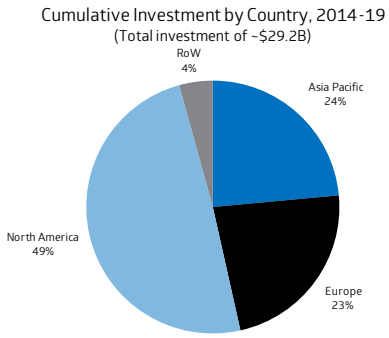
which accounted for 50% of all investment spending from 2014-2019 (when we exclude self-driving and medical robotics), while Europe accounted for ~23%, Asia Pacific 24%, and Rest of the World 4%. This is a marked change from the traditional robotics paradigm, where large companies in Europe and Asia (Japan most notably) dominate and represent ~80% of global supply.

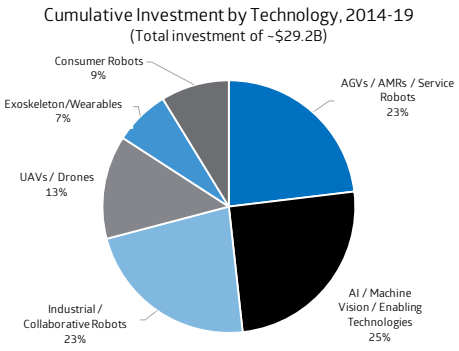
The most significant portion of investment growth been directed towards the following areas: AGVs/AMRs/Service Robots (23% of spend or ~$7.1B), Enabling technologies, which includes things like AI, Deep Learning, Machine Vision and LiDAR (25% of spend or ~$7.6B) and Industrial/Collaborative Robots (22% of spend or ~$6.7B) – collectively these groups represent 70% of total investment into robotics from 2014-2019.

Figure 12 Significant Investment Growth Into Robotics Over The Last 6 Years - AGVs/AMRs (Mobile Robots), Enabling Technologies, And Industrial / Collaborative Robots Have Received the Majority Of Investment Dollars

	2014	2015	2016	2017	2018	2019	5yr CAGR
AGVs / AMRs / Service Robots	$98	$412	$732	$1,329	$1,203	$2,972	98%
AI / Machine Vision / Enabling Technologies	$190	$735	$445	$1,860	$1,730	$2,387	66%
Industrial / Collaborative Robots	$54	$703	$790	$1,039	$3,611	$418	51%
UAVs / Drones	$318	$553	$591	$785	$750	$874	22%
Exoskeleton/Wearables	$36	$124	$14	$764	$100	$1,038	96%
Consumer Robots	$135	$218	$301	$526	$1,144	$229	11%
Total Investment	$831.1	$2,744.9	$2,872.9	$6,301.6	$8,537.9	$7,917.1	







Source: PitchBook, Cowen and Company

The ramp we're seeing in investment correlates well to the inflection on the deployment side as well, particularly within the warehouse/logistics sector (which currently makes up ~40% of the total professional robotics market).

According to World Robotics, the number of logistics robot systems deployments increased 60% to 110.8k units in 2018. They estimate that between 2019 – 2022 the installed base of logistics robot systems will increase at a 3-year CAGR of ~59% and equate to 1.61MM new deployments. For context, this would be over 6x the entire global operating stock of logistics robots that were deployed between 2012-2018. There are several contributing factors to this type of rapid growth, including: factories becoming increasingly more digitalized, performance and improvement of robot navigation (less reliant on beacons and physical infrastructure and are closer to having fully autonomous navigation systems), increased uptimes with shorter recharging cycles as batteries and energy storage technologies improve, an increasingly positive

reputation of AGV/AMR usage, and ease of setup and configuration. We'd note that forward estimates – which World Robotics highlights should be considered minimum numbers – were revised materially higher in 2019 vs. the 2018 report. Total logistics related demand over the 2019-2021 period is now expected to reach nearly $29B, up over 60% from last year's estimate.

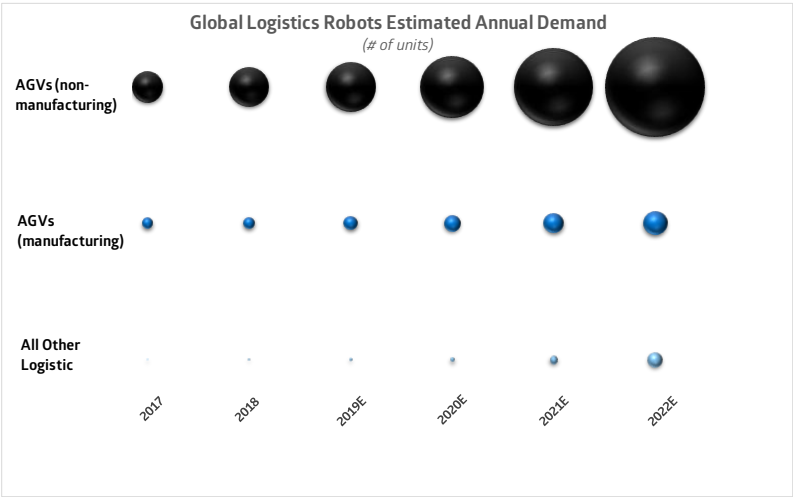
Figure 13 Estimated Annual Global Demand For Logistics Robots – The Majority Of Expected Growth Will Come From Non-Manufacturing AGVs (Mobile Robots)

Global Logistics Robotics Estimated Annual Unit Demand
(in # of units)

	2017	2018	2019E	2020E	2021E	2022E
AGVs (non-manufacturing indoor)	62,191	102,959	164,079	261,644	417,586	666,940
AGVs (manufacturing)	7,052	7,702	11,217	16,035	23,190	33,933
All Other Logistic Robots	74	203	403	982	3,008	11,026
Total Number of Logistics Robots	**69,317**	**110,864**	**175,699**	**278,661**	**443,784**	**711,899**
y/y growth		*59.9%*	*58.5%*	*58.6%*	*59.3%*	*60.4%*

Global Logistics Robotics Estimated Annual $ Value
(in $ '000)

	2017	2018	2019E	2020E	2021E	2022E
AGVs (non-manufacturing indoor)	$1,914,123	$3,142,416	$4,984,040	$7,929,024	$12,649,335	$20,242,864
AGVs (manufacturing)	$478,315	$504,338	$719,944	$961,574	$1,346,014	$1,921,900
All Other Logistic Robots	$3,819	$12,603	$23,078	$44,626	$101,857	$286,708
Total Logistics Robot Value	**$2,396,257**	**$3,659,357**	**$5,727,062**	**$8,935,224**	**$14,097,206**	**$22,451,472**
y/y growth		*52.7%*	*56.5%*	*56.0%*	*57.8%*	*59.3%*



Source: World Robotics 2019, Cowen and Company

As investment trends would suggest, the US is the global supply center for these types of robots – and has satisfied ~80-90% of global demand over the past 5 years. It's an interesting position for the US as foreign policy becomes more nationalistic – supplying nearly all of global demand but accounting for roughly 1/3 of it. It's an enviable spot to be in, and discussions on trade and IP will be interesting regarding this type of technology considering such material leadership.

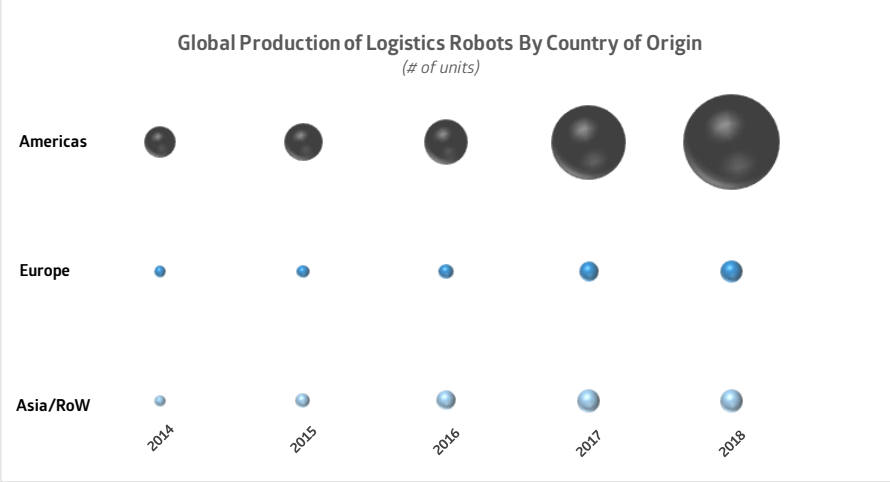
Figure 14 Logistics Robot System Production By Country Of Origin – The Americas Have An Impressive Lead

Logistics Robots Production by Country of Origin
(in # of units)

	2014	2015	2016	2017	2018
Americas	10,316	15,422	20,483	60,577	100,852
Europe	1,206	1,560	2,279	3,495	4,676
Asia/RoW	1,130	2,036	3,532	5,245	5,336
Total	12,652	19,018	26,294	69,317	110,864

(% of Production)

	2014	2015	2016	2017	2018
Americas	*82%*	*81%*	*78%*	*87%*	*91%*
Europe	*10%*	*8%*	*9%*	*5%*	*4%*
Asia/RoW	*9%*	*11%*	*13%*	*8%*	*5%*



Source: World Robotics 2019, Cowen and Company

Will Market Leaders Mature Organically Or Become Part Of Larger Organizations?

Investment Consideration #3: Historical precedent of forward-looking companies acquiring robotics leaders, utilizing tech internally, and creating market voids.

As we've discussed, private capital for robotics startups is there. History has, so far, shown us that the most successful and scaled of these businesses tend to be acquired by larger organizations looking to gain an internal competitive advantage. For now, M&A continues to be the more likely path for successful companies in the space, rather than scaling more materially towards solo entry into public markets.

Amazon's $775MM purchase of Kiva systems was perhaps the highest profile – and it created a commercial void for mobile robot technology that the market (and AMZN's competitors) had to scramble to fill. Amazon made the decision to use the technology internally only, as opposed to also selling it to other interested parties. However, Kiva's roots have spread throughout the industry and spawned many similar companies led by individuals formerly associated with Kiva.

More recently, Shopify acquired 6 River Systems (one of those companies with Kiva roots) for $450MM. Management believes the technology (autonomous carts used largely in warehouse/fulfillment applications to help workers fill, count, replenish, and sort more effectively) can boost productivity by 2-3x that of manual processes alone. The company appears set to take a different approach than Amazon, and intends to operate, build, and sell 6 River Systems solutions. 6 River lists companies such as XPO

and DHL as customers, so it will be interesting to see if/how this view evolves as those contracts move towards expiration – will demand have to be met elsewhere?

Figure 15 List Of Notable Investments/Acquisitions Of Mobile Robots By Category

Company Name	Description	Region	Cumulative Funding ($MM)	Valuation ($MM)	Last Funding
AGVs / AMRs / Service Robots					
Nuro	Developer of a suite of fully autonomous vehicles for local goods delivery.	North America	$1,032	$2,700	Feb-19
CloudMinds	Offers a cloud based platform to connect & control robots. Offers various autonomous robots.	North America	$817	$817	Jul-19
Amazon Robotics	Developer of AMRs & AGVs for logistics fulfillment. (Formerly Kiva Systems)	North America	$809	$809	Aug-12
AutoStore	Developer of an automated storage and retrieval system which uses AGVs for collecting stored goods in a warehouse.	Europe	$523	$646	Jan-17
Welltec	Developer of robotics designed for well technologies and services for the O&G industry.	Europe	$504	$870	Feb-16
6 River Systems	Developer of AMRs to assist w/fulfillment process for e-commerce and retailers. (Acquired by SHOP)	North America	$497	$497	Oct-19
Endeavor Robotics	Developer of UGVs used for applications such as miliary, law enforcement & industrial settings.	North America	$432	$432	Mar-19
FMC Schilling Robotics	Manufacturer of high tech sub-sea systems including ROVs, manipulators & custom systems.	North America	$397	$511	Apr-12
Liquid Robotics	Developer of UAVs. Provides ocean data services utilizing autonomous surface vehicles.	North America	$382	$382	Dec-16
SoftBank Robotics EU	Produces autonomous commercial floor cleaning robots. Also develops autonomous humanoid service robots.	Europe	$350	$1,180	Jun-15
Mobile Industrial Robots	Manufacturer of collaborative AMRs. Used in a wide range of industries & healthcare sectors to automate in-house transportation.	Europe	$275	$275	Apr-18
Geek+	Developer of AMRs and AGVs for logistics & warehouse fulfillment purposes, including storage, movement & sortation.	Asia Pacific	$203	-	Jun-19
Aethon	Developer of AMRs for delivery purposes. Used to transport medications, meals & supplies.	North America	$199	$199	Jan-19
GreyOrange	Developer of AMRs and AGVs for logistics & warehouse fulfillment purposes, including storage, movement & sortation.	Asia Pacific	$179	-	Sep-18
AI / Machine Vision / Enabling Technologies					
UiPath	Developer of robotic process automation software designed to enhance performance.	North America	$977	$7,100	Apr-19
Horizon Robotics	Provider of embedded AI chips/technology designed to create the brain of things, for safety, convenience and fun.	Asia Pacific	$700	$3,000	Feb-19
Atlantic Inertial Systems	Manufacturer of inertial sensors used for control, navigation and guidance.	North America	$515	$515	Dec-09
Blue River Technology	Developer of a next generation smart agriculture equipment that utilizes computer vision & AI.	North America	$336	$336	Sep-17
Unisound	Developer of IoT AI technology in the area of voice recognition and language technology.	Asia Pacific	$303	$333	Apr-19
Pacific Control Systems	Provider of end-to-end managed application services and technologies for M2M & IoT.	RoW	$272	-	Apr-15
Adept Technology	Provider of vision-guided robotics systems & services.	North America	$218	$218	Oct-15
Servotronix Motion Control	Developer and distributor of customized and standard motion electronics products.	Asia Pacific	$170	$170	Feb-17
Consumer Robots					
Ubtech	Developer of humanoid robots designed to integrate robots into the daily lives of everyone.	Asia Pacific	$1,010	$5,000	May-18
Rokid	Developer of a smart home devices. Also develops mixed reality wearable glasses.	Asia Pacific	$178	$450	Jan-18
Robopolis	Manufacturer of robots designed to help with household floor cleaning & vacuuming.	Europe	$150	$150	Oct-17
Sphero	Developer of application based droids/robots for educational purposes.	North America	$132	-	Aug-19

Company	Description	Region	Cumulative Funding ($MM)	Valuation ($MM)	Last Funding
Exoskeleton/Wearables					
CTRL-Labs	Developer of neural interface platform designed to increase the interactive capabilities of devices.	North America	$1,067	$1,067	Sep-19
Ottobock	Developer of prosthetic limbs created to improve the mobility of people with disabilities.	Europe	$740	$3,700	Nov-17
Innophys	Developer of an nurse-care & welfare exoskeletons to be used for physical support.	Asia Pacific	$105	-	Aug-15
Sarcos Robotics	Developer of mobile tele-operated robots designed to augment worker performance. Developing an exoskeleton system.	North America	$46	-	Sep-18
SuitX	Developer of robotic exoskeletons created for industrial & medical markets.	North America	$25	$60	Sep-18
Industrial / Collaborative Robots					
Piab	Manufacturer of automation products. Offers various gripping solutions & EOAT products.	Europe	$1,145	$1,145	Jun-18
Coesia	Designer & manufacturer of automated machinery, industrial process solutions, & precision gears for various industries.	Europe	$584	-	Jul-18
Gimatic	Manufacturer of pneumatic & electric grippers for industrial automation.	Europe	$564	-	Oct-18
Automation Anywhere	Provider of RPA software designed to augment the human workforce by automating repetitive business processes.	North America	$550	$2,600	Nov-18
Universal Robots	Developer of collaborative robotic arms.	Europe	$352	$352	Jun-15
Kensington Labs	Manufacturer of advanced high-throughput, sub-micron motion control equipment for various applications.	North America	$275	$275	Feb-01
Bastian Solutions	Provider of independent system integration designed to provide turnkey solutions.	North America	$260	$260	Apr-17
Bright Machines	Developers of an intelligent manufacturing software platform designed to automate manufacturing operations & robotics.	North America	$229	$679	Oct-18
UAVs / Drones					
Aeronautics	Develops & manufactures UAVs, electro-optical systems and communications.	RoW	$659	-	Feb-19
The Insitu Group	Manufacturer of unmanned air systems for intelligence, surveillance and reconnaissance.	North America	$459	$459	Sep-08
Zipline Int'l	Provider of drone delivery service to deliver medications to health facilities around the world.	North America	$304	$1,320	May-19
Aeryon Labs	Manufacturer of small UAVs for reliable performance in extreme weather & winds.	North America	$247	$247	Jan-19
Zero Zero Robotics	Developer of autonomous flying cameras.	Asia Pacific	$201	-	Nov-18
3DR	Provider of smart drones intended to offer site scanning and land mapping services.	North America	$186	-	Jun-19
SZ DJI Technology	Manufacturer of unmanned drones & camera support accessories.	Asia Pacific	$145	-	Nov-17

Source: PitchBook, Company reports, Cowen and Company

Company Specific Deployments In The News

XPO: In October 2018, XPO Logistics announced plans to deploy 5,000 intelligent robots from GreyOrange in logistics sites throughout North America and Europe. The robot

deployments are collaborative in nature, are designed to supplement XPO's existing workforce and are intended to support future growth of the company. CEO Brad Jacobs said "The addition of 5,000 collaborative robots will make our logistics operations safer and more productive in picking, packing, and sortation. These are important benefits for our customers - particularly in the e-commerce and omnichannel retail sectors, where order speed and accuracy are essential ways to compete."

At the time, this deployment was part of XPO's planned $450MM investment in technology for 2018. According to a report from FreightWaves in October 2018, XPO has worked with 29 robotics companies and deployed over 70 different types of robots across their warehouses. The article also said that XPO has deployed robot systems from vendors such as 6 River Systems and KUKA's Swisslog.

FedEx: FedEx is spreading out its robotics investments on different package delivery technologies, including last-mile delivery autonomous robots, autonomous trucks, and drones. Recently it rolled-out a protype called FedEx SameDay Bot, and it will begin testing in Memphis later this year. The robot is being developed in collaboration with DEKA Development & Research Corp and its founder Dean Kamen, who also invented the Segway. On the autonomous trucking front, FedEx has partnered with Peloton Technology, which uses semi-autonomous electronically linked truck platoon systems, and it is also working with Daimler and Volvo to develop the technology for autonomous delivery services. They believe this can be implemented within the next 10 years. FedEx has also tested drone deliveries, having partnered with Alphabet owned Wing Aviation, and recently completed the first eCommerce delivery-via-drone trials in the U.S, where they are testing deliveries in qualifying homes in Christiansburg, VA.

Figure 16 FedEx's SameDay Bot

Source: FedEx

UPS: Like FedEx, UPS has been focusing on and investing in delivery challenges, specifically on self-driving trucks and drones (less so on actual robots). Earlier this year, they invested in an autonomous trucking company called TuSimple and together the companies will test self-driving tractor trailers on a route in Arizona. The company believes they can reduce transportation costs by 30%. With respect to drones, UPS has partnered with CVS to deliver prescription drugs to customer doorsteps. It recently launched *UPS Flight Forward,* which is their dedicated division focused on autonomous

drone delivery. It has also received the FAA's approval to operate a drone airline. The company is currently focusing its efforts on the healthcare industry given the time sensitive nature of critical-care or lifesaving applications. The drones are manufactured by a California-based company called Matternet.

JD.com: The largest online Chinese retailer has a vast fulfillment network, much of which is highly automated as a result of heavy investments in robotics. JD.com has the largest fulfillment infrastructure of any eCommerce company in China, operating 500 warehouses (approximately 130m sq. ft.) and a total of 6,906 delivery stations and pickup stations. The company also owns most of its last-mile network. In Shanghai, it has opened a fully automated fulfillment center it calls *JD Asia No 1 Warehouse*, and the company plans to open 6 more of these in the near future. The company is considering using drones to deliver packages to less urbanized cities, given the lack of infrastructure makes it hard to access some of these places efficiently. As a result of their vast investments in their logistics network, the company offers same day delivery (sometimes within two hours) for many of their products in the biggest cities.

Cowen/MassRobotics 2019 Robot Manufacturer And User Survey Results

Investment Consideration #4: Our survey suggests a meaningful near-term product introduction cycle, good manufacturer/user alignment, but disparity on cost/value proposition.

We partnered with MassRobotics to conduct a survey of ~20 robot manufacturers / end users across the US, Europe, and Asia and gain proprietary insight into this rapidly expanding market. Our broader findings are detailed below, but our 3 primary takeaways are: **1)** alignment between what end-users want and what manufacturers are working on appears strong; **2)** new product introduction is poised to accelerate materially in the very near-term; and **3)** a key deployment headwind seems solvable through increased communication / education.

Investment dollars to support innovation and market dynamics that favor adoption are great – so long as the technologies being developed match the wants/needs of the customer base. Potential customers are looking for solutions around product movement, handling, and delivery (24% of respondents), quality/inspection (18%), pick and place (15%) and inventory management (15%). These top 4 desires represent ~75% of all responses. Our survey suggests nice alignment, with those solutions representing over 80% of responses on the manufacturer side and notably product movement, handling, and delivery was comfortably the top response for both parties.

Figure 17 Product Solutions Are Geared Towards Product Handling/Movement…

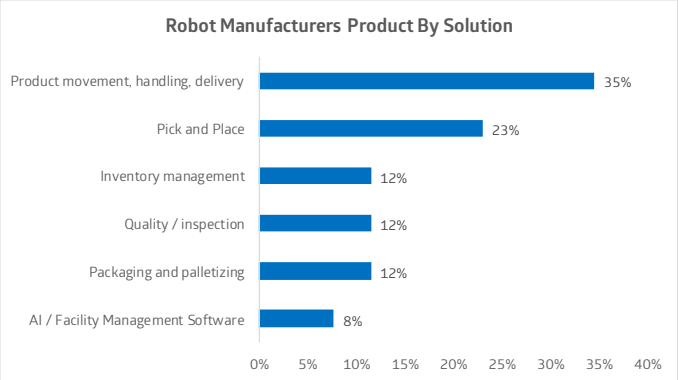
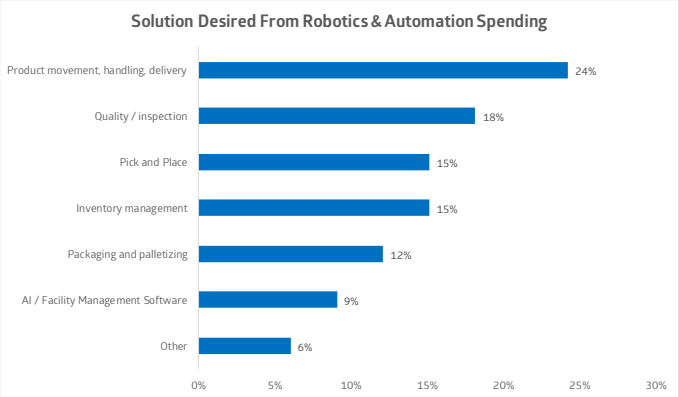


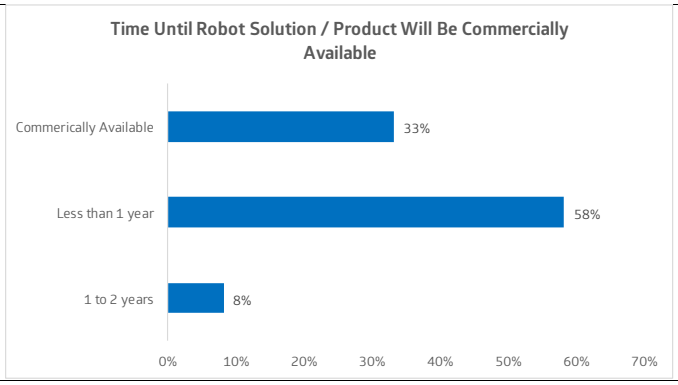
Figure 18 … Which Aligns With Desired Solutions From Potential Corporate Customers



Source: MassRobotics and Cowen and Company 2019 Robotics Survey

In terms of timing, a third of respondents have products already commercially available, with another 60% expecting to be commercially available in less than one year. Less than 10% believe they are more than 1 year out.

Figure 19 Nearly All Participants Have Or Will Have Products Commercially Available Within One Year



Source: MassRobotics and Cowen and Company 2019 Robotics Survey

One of the more interesting takeaways from our survey was the opinion-based response to our question on why we have yet to see higher levels of robot adoption in commercial settings, despite more technology use in our everyday lives. Interestingly, manufacturers believed that corporations have not had a higher level of robot utilization due to skepticism over the reliability and consistency of systems (23% of respondents), while this concern was cited by only 5% of surveyed corporate robot users. End users believe that high capex costs to deploy and maintain robot systems/solutions is the top hindrance to further deployments. We believe that further evidence of attractive paybacks on installations (which manufacturers generally cite as well under 2 years) can help alleviate what is now a top concern for potential users.

Figure 20 Manufacturers Believe Reliability And Uncertain Efficiency/Productivity And Throughput Gains Are Hindering Robot Deployments…

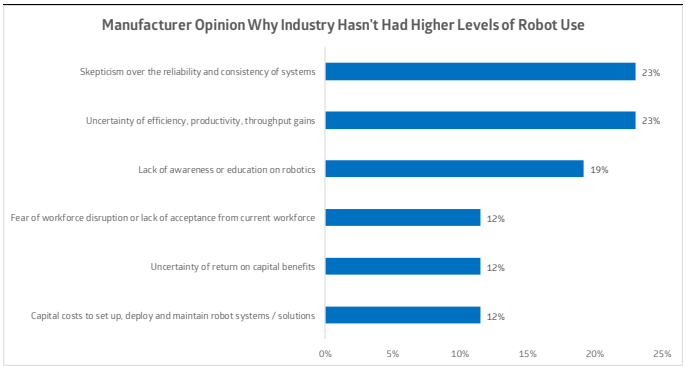
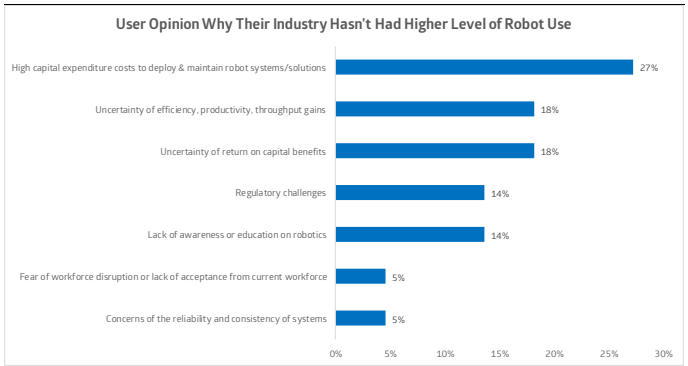


Figure 21 … While Users Believe High Capex Costs To Deploy And Maintain Systems Are The Biggest Headwind



Source: MassRobotics and Cowen and Company 2019 Robotics Survey

Further supporting our view that end-user concerns about high costs to deploy is an inherently solvable problem is that nearly all participants expect to increase robotic/automation capex over 2021-2023 vs. 2020 levels. Nearly 40% expect to increase robotic investment by 20+%, while only 13% expect spending levels to remain roughly flat.

Figure 22 88% Of Users Are Expecting A Larger Portion Of Capex To Be Directed Towards Robotics/Automation Between 2021-23

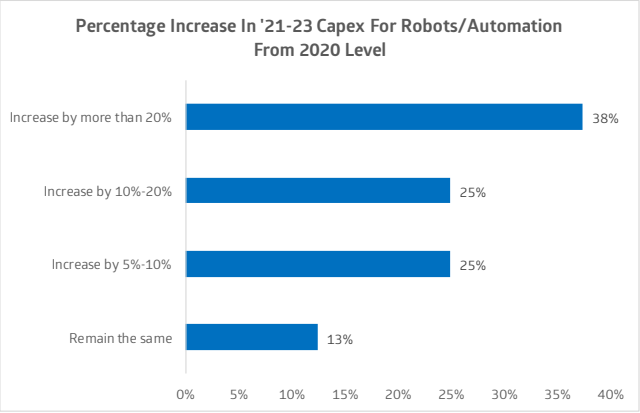
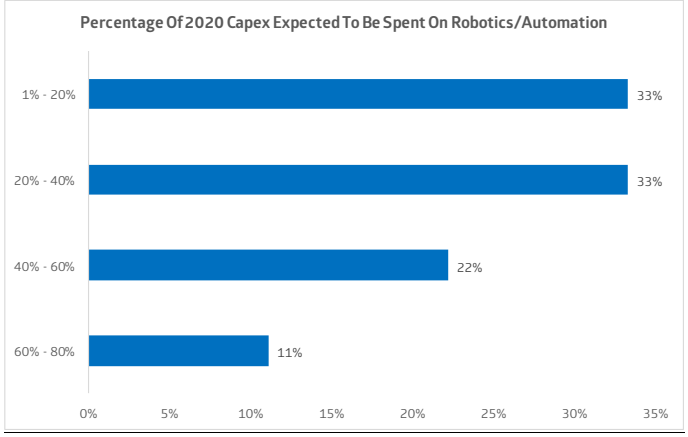


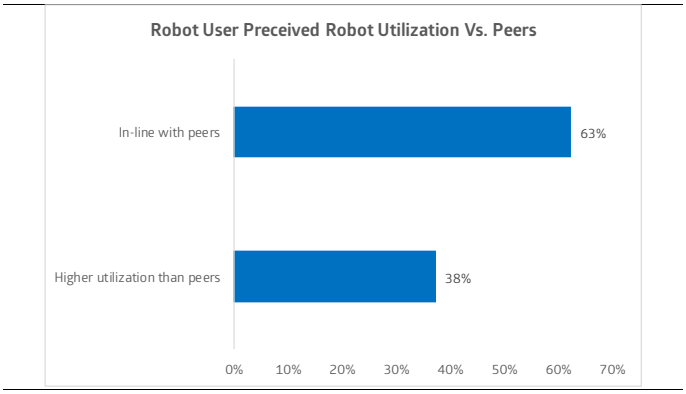
Figure 23 66% Expect To Spend Over 20% Of Total Capex On Robotics/Automation



Source: MassRobotics and Cowen and Company 2019 Robotics Survey

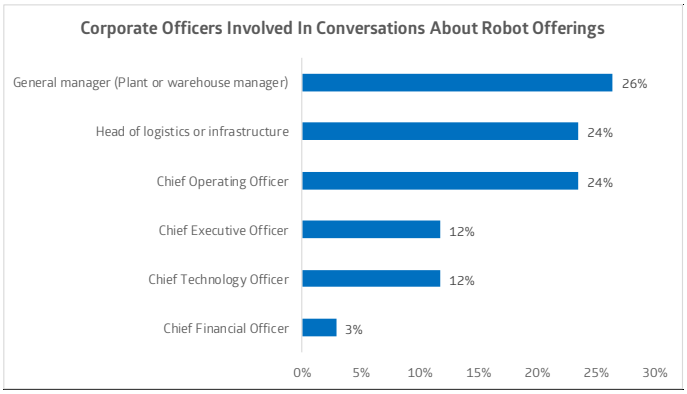
Less than 40% of respondents thought their level of robotics utilization was above peers and none thought they were behind. This suggests that the 60% in the middle believe they have deployment upside in order to gain a robotics advantage vs. peers. When we asked robot manufacturers who their primary counterparts were on the end-user side responsible for decision making, ~50% said plant/warehouse general manager or head of logistics/infrastructure – a good sign that those closest to and most familiar with the technology are the ones empowered to make the decision. Another 24% identified the COO as the primary target.

Figure 24 Over 60% View Themselves "In Line" In Terms Of Deployment Vs. Peers – Suggesting Upside To Gain Advantage



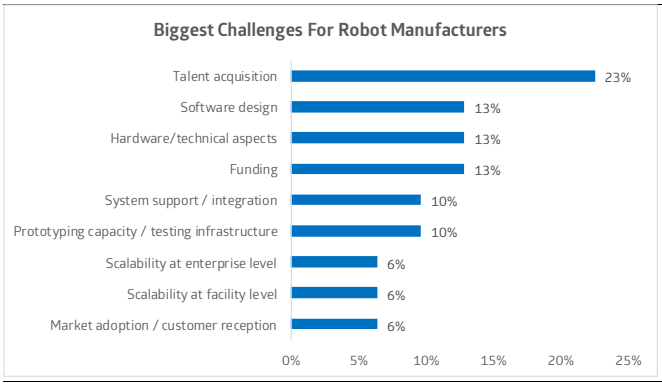
Source: MassRobotics and Cowen and Company 2019 Robotics Survey

Figure 25 Most Decisions Made By Those Closest And Most Familiar To The Technology



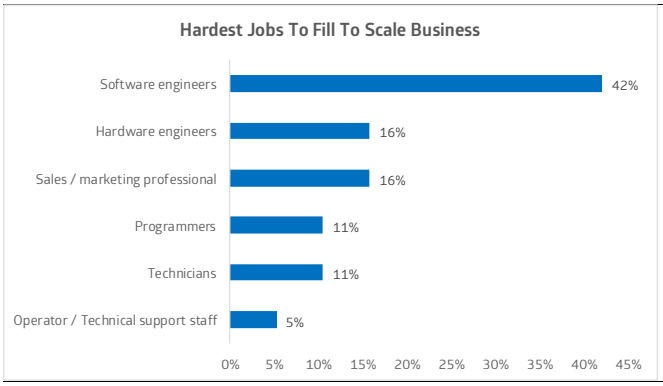
One potential bottleneck to keep an eye on as robotics manufacturers scale to meet demand from a more receptive customer base is talent, which was cited as the #1 challenge facing robot manufacturers as they grow. Software engineers were overwhelmingly identified as the hardest job to fill.

Figure 26 Talent Acquisition Was The Most Widely Cited Challenge Robot Manufacturers Face To Develop Their Solution…



Source: MassRobotics and Cowen and Company 2019 Robotics Survey

Figure 27 …With Software Engineers Overwhelmingly The Most In Demand Position



Rage Against The Machine - Examining the Human Element of Robot Deployment, Part II

Investment Consideration #5: Robotics taking jobs in this sector is an absolute fallacy – data shows a vibrant and tight warehouse labor market despite robotics deployment.

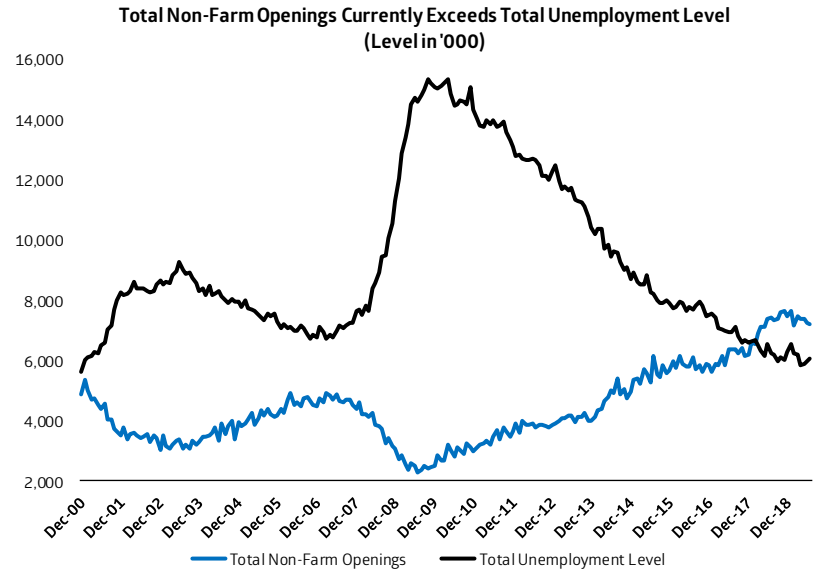
In Part I of our robotics series (HERE) we discussed the interplay between robotics deployment and labor trends within the broader manufacturing industry and made the point that despite a tripling of the robotics installed base over the past 10 years manufacturing job openings as a % of total manufacturing jobs has doubled. While there is generally a near-term displacement as transformational technology is brought in, ultimately what is replaced is a skill set rather than a job itself. Simplistically, the deployment of robotics leads to less humans needed per item produced, but allows for

lower cost production and a rapid expansion of total volumes, which supports total job expansion – this is what we've seen in markets like autos over time.

"Most of the research seems to suggest that the direction that automation is moving in is the displacement of skills, not jobs," says R. David Edelman, formerly President Obama's special assistant on the digital economy, and now the director of MIT's Project on Technology, Economy, and National Security. "That suggests those individuals can, by Amazon, be reskilled or leverage other skills they already have in the same job."

As a backdrop to our labor discussion, it's important to point out that our starting point today is a labor market where total job openings exceed total unemployment and suggests an underlying tightness of labor supply, at least in the near-term. Within the warehouse sector in particular, the current workforce is older than the national average (~30% are 55 or older vs. closer to 25% for the national average) and the job is more dangerous (50% more injuries per 100 employees vs. national average) – likely exacerbating tight labor supply in an already stretched environment.

Figure 28 Underlying Labor Tightness As Job Openings Exceed Total Unemployment

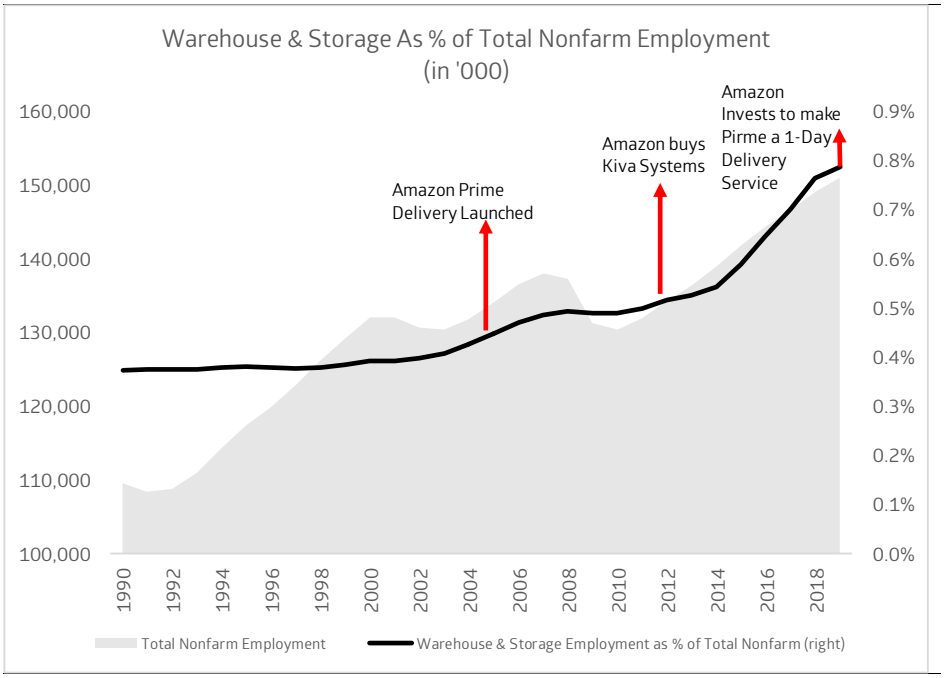


Source: Bureau of Labor Statistics, Cowen and Company

US Data Suggests A Strong Warehouse Labor Market Despite Robotics Investment And Implies Additional Automation Is Likely Required

As we noted earlier, eCommerce sales have expanded 20x since 2000 and warehouse employment has tripled to support the incremental fulfillment demand. Amazon was a first mover in terms of meaningfully adopting robotics into its logistics process, and interestingly since their purchase of Kiva in 2012, we've seen a material inflection higher in warehouse hiring as a % of total – which on the surface seems counterintuitive. Warehouse employment as a % of total nonfarm employment has roughly doubled since 1990, but the bulk of that relative increase has come in the past several years.

Figure 29 Warehouse & Storage Jobs As A % Of Total Jobs Continues To Increase – Interestingly, The Biggest Inflection Was Following Amazon's Purchase Of Kiva Systems In 2012



Source: Bureau of Labor Statistics, Cowen and Company

Amazon announced the creation of Prime membership in 2005, offering free 2-day shipping within the contiguous United States on all eligible purchases and discounted one-day delivery. The advent of Amazon Prime coincided with the first notable uptick in warehouse employment as a % of total employment. It is worth highlighting that ~53% of the increase occurred from 2012 to present – which coincides with Amazon's purchase of Kiva Systems in mid-2012 and the true beginning of the company's robotics journey. Earlier this year, Amazon announced it would be investing $800MM during the second quarter of 2019 to improve warehouses and delivery infrastructures as they try to evolve "Prime" into a free one-day delivery program.

While actual warehouse employment has improved significantly in both gross and relative terms, hiring trends remain strong despite accelerating deployment of logistics robots broadly. Total warehouse related job openings as a percentage of total employment in the sector stand at nearly 20-year highs on a much larger employment base.

Figure 30 Transport And Warehouse Job Openings Growth Has Kept Pace With Logistic System Deployments Over The Last 7 Years…

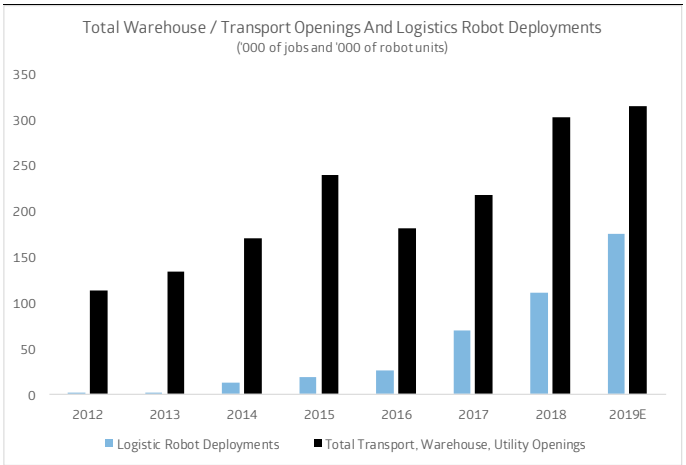
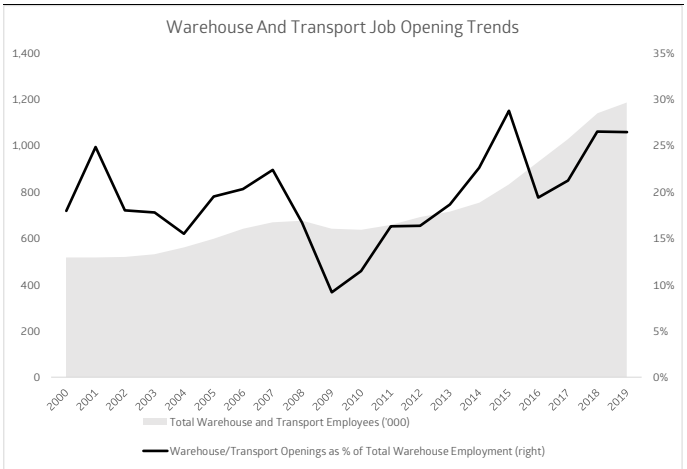


Figure 31 …And Openings As A % Of Total Warehouse And Transport Employment Remain Near 20-Year Highs

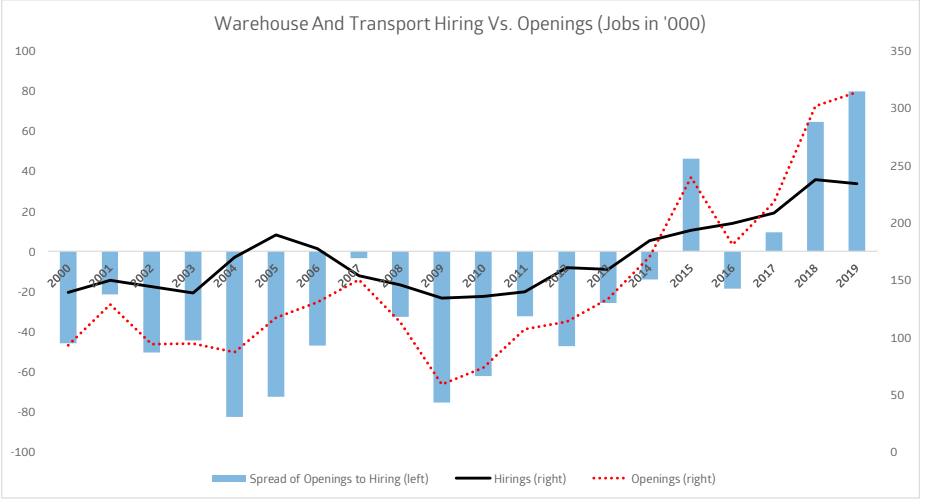


Source: Bureau of Labor Statistics, Cowen and Company

Do rising job openings suggest the jobs being created in the wake of more robot deployment are harder to fill or less desirable? The answer isn't that straightforward (robotics tends to replace repetitive jobs with a combination of lower level, non-repetitive jobs and higher-level management jobs), though hiring and wage trends in the industry do suggest movement in the right direction.

Over the past 5 years (ending in 2018), warehouse related hiring grew at a nearly 8.5% CAGR vs. the broader private market at ~4.5%. Warehouse growth in 2018 was 14% and was the biggest year since 2000 in terms of gross hiring. Despite outsized hiring growth, the spread of warehouse openings to hiring continues to widen.

Figure 32 Hiring And Openings Are Continuing And The Spread Between Both Is Continuing To Rise, Highlighting The Labor Challenges Faced By The Warehouse And Transport Industry



Source: Bureau of Labor Statistics, Cowen and Company

It's possible that some of that widening gap is temporary as certain parts of the labor force are trained to fill newer jobs that have been created. Wage trajectory in the warehouse sector, however, suggests an employer push to narrow this spread and attract new talent and supports our view that, in aggregate, better and higher paying jobs are being created within the warehouse & storage sector.

Over the past 10 and 20 years, warehouse & storage wage growth lagged the private sector by 43bps and 128bps, respectively. However, over the past 5 years warehouse and storage wages have outpaced the private sector by 105bps. Over the last 3 years that positive spread widened further to 248bps.

We would note that Amazon increased its minimum wage to $15/hour for all US employees effective November 2018 and this could account for some of the recent wage outperformance. The increase in wages could also be viewed as an attempt by employers to attract workers to an industry that is facing substantial labor shortages. A 2018 survey from Logistics Management found that 55% of respondents (a 6% increase from the 2017 survey) cited the inability to attract and retain a qualified hourly workforce as their leading issue. The data overall suggests that continued deployment of robotics solutions will be required over time as accelerating wages and hiring appear to be unable to keep pace with required demand (openings) on its own.

Figure 33 Sizable Improvement In Relative Wage Performance Which Coincides With Increased Robot Deployments In Logistics And Warehouses

Average Annual Wage Growth	3 Year	5 Year	10 Year	20 Year
General Warehousing and Storage	3.2%	2.3%	0.2%	-0.6%
Total Private Sector	0.7%	1.2%	0.6%	0.7%
Warehousing & Storage Spread (bps)	248	105	(43)	(128)

Source: Bureau of Labor Statistics, Cowen and Company

Primer - Warehouse Robots

World Robotics classifies a logistics system as one that manages the flow of goods, their transport, handling, and packaging. One thing that all logistics systems have in common is they require mobility in both indoor and outdoor environments. Automated/Autonomously Guided Vehicles (AGVs) and Autonomous Mobile Robots (AMRs) are a class of mobile robots that are used in various applications, industrial and non-manufacturing, to automatically move materials from one point to another.

AMRs and AGVs are typically installed in industrial environments for moving work-pieces including boxes, pallets, and tools between machinery, transfer points, or storage. In non-manufacturing environments such as warehouses, airports, and logistics centers, they are used to deliver and transport goods. The main benefit from robotic systems utilized in logistics is increased efficiency, reduced error and return rates, improved safety, collaboration with human workers, and faster delivery and product movement rates.

Applicability In Warehouse Applications

Warehouses are chaotic and not typically pre-defined - the items stored within vary in size, shape, weight, material, etc. At the same time, there is an infinite number of possible paths to navigate and item combinations that are completely dependent upon customer orders. In order to fulfill these orders efficiently and meet tight timelines, robots, automation, and warehouse management software are required to work seamlessly alongside human employees. Robots/automation leverage a host of enabling technologies (discussed in more detail shortly) including machine vision, LiDAR, 3D cameras, SLAM (simultaneous localization and mapping), cloud computing, AI, and machine/deep learning.

Figure 34 Challenges Faced By Warehouses And Fulfillment Centers That Robotics Can Help Address

Faster Throughput	More packages moving through the same distribution center, higher turnover and fulfillment.
Reverse Logistics	The process of moving good from the customer back to the distributor, for example for repairs or returns. The product thus, travels in reverse on the supply chain.
Return Handling	Similar to reverse logistics, but products are sent back to the manufacturer, not for repair but permanently given the customers' dissatisfaction.
Value-Added Services	Product assembly, packing, labeling, and repairs.
Storing Diverse Products	E-commerce retailer may house millions of SKUs versus traditional retailers that have tens of thousands.
Seasonal Demand Volatility	Volumes in peak season (November 1st to December 20th) spiking by 4-5X vs. the average shipping volume.
Last Mile Challenges	The "last mile" can account for as much as 30% of a product's transportation expense and remains very labor intensive.

Source: Cowen and Company

Types Of Robots

Automated Guided Vehicles (AGV) are used to transport goods throughout the warehouse by following markers or other navigational guides. They have been used for over 50 years in warehouses and manufacturing plants. Traditionally, AGVs rely on fixed infrastructures such as reflectors, tags, and floor markings, but as technology has advanced have become increasingly more dependent on radar and camera systems along with sensors and software that help the guiding process and adaptation to the environment.

Autonomous Mobile Robots (AMR) differ from AGVs by their degree of autonomy and are also known as ***mobile collaborative robots*** given that most can work closely with workers. They are more sophisticated as they don't require floor markings, navigating instead using preloaded facility maps and more advanced versions can learn the environment themselves using Deep Learning techniques. They also adjust appropriately to accommodate employees moving within their paths. Technologies like advanced sensors enable these robots to adjust to their surroundings and correct errors they may encounter, ultimately establishing a digital record of the physical environment they operate in.

End-Markets For AMRs

Warehousing/Logistics: AMRs in warehouses are used to transport goods, both physical products as well as packaged. Different types of AMRs can do different tasks such as picking, sorting, moving and dropping packages. In the future, it is possible that AMRs completely replace the traditional conveyor system given that they lack flexibility that the AMR has. There are different types of AMRs used in warehouses such as:

- **Fully automated AMRs** which can pick, move and/or drop packages at different locations of the warehouse without any human interaction. They typically pick the goods from a picking station that they are familiar with and connected to.

Figure 35 Amazon Robotics AMR (Kiva Systems)

Source: Amazon Robotics

Figure 36 6 River Systems AMR

Source: 6 River Systems

Pick carts can follow workers around the warehouse and aid them in picking and transporting products. They typically have a cart on the top on which workers place products or packages.

- **Autonomous Mobile Manipulation Robots (AMMR)** are a type of AMR that includes a smart, robotic arm for material handling such as picking from a mobile platform.

Figure 37 IAM Robotics AMMR For Autonomous Picking

Source: IAM Robotics

- **Autonomous Forklifts** aimed at replacing forklifts which are operated by humans to carry pallets.

Figure 38 Geek+ Autonomous Forklift

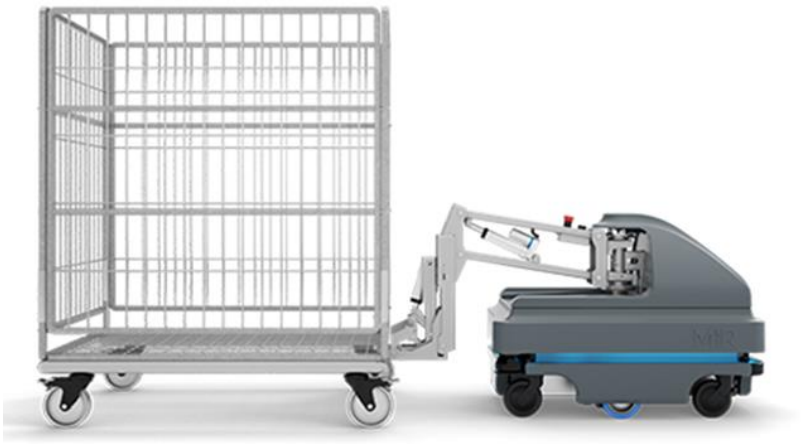
Source: Geek+

- **Inventory Trackers** move around the warehouse tracking inventory using RFID technology and work in conjunction with software packages to store and analyze the data to manage the inventory.

Retail: Retailers mainly use AMRs for in-store inventory checking as well as other tasks such as mopping floors. On the eCommerce side, another emerging type of AMR is focused on last-mile delivery which is typically the most expensive part of the delivery chain. These AMRs are intended to carry packages and deliver them to the customer's door, moving along sidewalks like pedestrians.

Manufacturing: AMRs used in the manufacturing space are mainly used to transport inventory in different stages (raw materials, work-in-progress or finished goods) as well as packaging materials and scrap. They usually require higher payloads given the nature of their products. There are AMRs that carry products directly on top of them while others can have carts attached to them.

Figure 39 MiR Robot Utilized For Materials Transportation Within A Manufacturing Warehouse



Source: MiR

Healthcare: Used mainly in hospitals, AMRs can be used to transport medical waste, patient meals, surgical/medical instruments and linens. They can be programmed to operate doors, elevators and trashes so their design can be more sophisticated.

Other Types of Warehouse Robots

- **Unmanned Aerial Vehicles (UAV or Drones):** Drones have the potential to shape the eCommerce and logistics industry in two areas: inventory management (such as tracking inventory in real-time) and shipping and delivery (i.e. transporting the goods). Various companies have been testing drones for these applications, and regulation will play a major role in terms of timing and magnitude of near-term deployment outside of in-facility applications.

- **Stationary Articulated Robots**: This is what most people picture when they think of an industrial robot: it has multiple axes, rotary joints, and various degrees of freedom. In warehouses, these robots can be used to manipulate

packages. Pick and place, palletizing and depalletizing are some types of jobs that can be replaced with articulated robots. Amazon uses a type of robot called palletizers, which stacks totes of products using computer vision and laser sensors. We went into greater detail in last year's Part I.

Figure 40 A KUKA Palletizing Robot

Source: KUKA

Companies That Manufacture Warehouse Robots

Figure 41 Key Players And Product/Service Offered

Key Players and Product/Service Offered	AGVs/AMRs	Stationary Articulated	Software/AI	RaaS*	Last Mile Autonomous	Package handling**
6 River Systems (owned by Shopify)	✓		✓			
Amazon Robotics (previously Kiva Systems)	✓		✓		✓	✓
Locus Robotics	✓		✓	✓		
Fetch Robotics	✓		✓	✓		✓
MiR (owned by Teradyne)	✓		✓			
Grey Organge	✓		✓	Starting in 2021		✓
Geek+	✓		✓			✓
IAM Robotics	✓					✓
Swisslog (owned by KUKA)	✓	✓	✓			✓
Boston Dynamics (owned by SoftBank)		✓				✓
Startship robotics					✓	
Celluveyor						✓
BrainCorp			✓			
CMC Machinery						✓
KUKA		✓				
FANUC		✓				
Wing (owned by Alphabet)					✓	

**Robot-as-a-service: full service subscription model (akin to renting) vs. outright ownership or leasing*
***Includes modular and flexible sortation systems*

Source: Cowen and Company

Amazon Robotics (formerly Kiva Systems): Amazon acquired Kiva Systems in 2012 for $775 million and decided to use the robots exclusively in-house, letting all their third-

party contracts expire. This gave them a significant first-mover advantage as there weren't many scaled alternatives in the market. The now ubiquitous orange robots known as "pods" are designed to move racks irrespective of size and shape, they are controlled by a centralized computer using a secured Wi-Fi network, use infrared technology to detect obstacles and cameras to read QR codes and determine location and direction. Additionally, the robots can self-adjust and learn from crowdsourcing that aggregates data from other pods. The company currently has over 200,000 deployed across its more than 300 fulfillment centers, a number which is expected to keep growing. This scale gives the company a major advantage versus other retailers. The company has stated that robots reduce warehouse operating expenses by roughly 20%. Another type of robot that Amazon has been developing (but not under Amazon Robotics) is in drones for delivery. The drone has a payload of 5 lbs and can travel 15 miles in 30 minutes or less.

6 River Systems (recently acquired by SHOP): The Boston based startup was founded by former Kiva employees and recently acquired by Shopify, the multi-channel eCommerce platform for small businesses, for $450mm. The company has estimated revenues of $30mm and expenses of $25mm, according to the Shopify press release. Its flagship robot, Chuck, is an AMR that works collaboratively with warehouse workers to accomplish fulfillment tasks by leading workers to items on the shelves, letting them know what quantity is needed, and carrying the selected items through the facility. It uses state of the art sensors, machine learning, and AI to move around and adjust to the environment. It can carry a maximum payload of 160 lbs. The company cites a 12-18-month payback. Users include Barrett Distribution Centers and XPO Logistics.

Locus Robotics: Locus offers a multi-bot pick system called LocusEmpower enabling higher pick rates with less labor. The robot is a goods-to-person robot where warehouse workers can place products on the robot's cart and the robot navigates to the next location. It offers their robots for an upfront fee and an ongoing subscription basis. It integrates with Warehouse Management System (WMS) software.

Fetch Robotics: Fetch offers a suite of AMR, a solution which they describe as On-demand automation given their ability to quickly deploy their products. Their robots can both transport and pick goods using attached arms, as well as scan inventory. The robot is built as a platform, so it is flexible enough to have different models built on top of it. The robots can be configured to work with WMS such as SAP's Extended Warehouse Management and use the data gathered by the software to configure and optimize the robots.

MiR (Mobile Industrial Robots – owned by TER): A Danish leading manufacturer of collaborative mobile robots, which designs and develops autonomous robots used by manufacturers across a wide range of industries to automate in-house transportation. The company offers various robots of varying sizes and payloads up to 1000 kg. MiR is owned by Teradyne, which acquired it in 2018 for $148MM and a maximum of $272MM including earn-out payments if certain sales-growth milestones are achieved. Teradyne has stated that MiR was profitable at the time of their acquisition.

GreyOrange: Manufactures and deploys advanced robotic systems for automation in warehouses, distribution centers, and fulfillment centers with over 70+ installations. Their flagship product is an AMR called Butler that automates put-away, inventory storage, replenishment, and order picking. Another solution is called Flexo, which is a modular flexible sortation system. They also offer a software called GreyMatter.

Geek+: Geek offers different robotics solutions for the logistics industry, including a picking system (goods-to-person), a storing system, a moving system, and a storage

retrieval system (basically an autonomous forklift). It has deployed over 200 projects worldwide and is based in Hong Kong.

inVia: inVia offers a Robot-as-a-Service solution for warehouses in a fully integrated way, primarily through AGVs that replace the manual storage and retrieval process. Their RaaS comprehensive solution is more attractive to customers as it reduces their CapEx and gives them more flexibility. The customer pays a subscription based on throughput and can increase or decrease the number of robots depending on the seasonal demand (robots are owned by inVia).

IAM Robotics: Fully automates piece picking and eCommerce fulfillment through automated material selection and transport. Their robot has an integrated arm and cart that picks goods and places them in the cart (an AMMR).

Swisslog (owned by KUKA): Swiss company specializing in integrated automation solutions for warehouses, distribution centers, and hospitals. It was acquired by KUKA in 2015. The company produces AMRs as well as an articulated robot called ItemPiq.

Boston Dynamics (owned by Softbank): A spin-off from MIT, Boston Dynamics has developed a number of robots and is currently owned by Softbank (previously Alphabet). In the robotic warehouse space, it developed an autonomous box lifting robot called Handle. It can unload trucks, build pallets, and move boxes throughout the facility. It also offers a stationary articulated robot called Pick which uses machine vision (2D and 3D) and deep-learning to build and depalletize mixed-SKU pallets. The company acquired Kinema Systems, a startup that uses vision sensors and deep-learning software to aid robots in manipulating boxes, to accelerate their entry into the logistics market.

Starship: A San Francisco based developer of self-driving robot delivery vehicles designed to assist in product delivery. Starship robots can deliver items within a 4-mile radius and are used to deliver parcels, groceries, and food from local stores. Deliveries can be requested via a mobile app, and once the order is placed, the robot's progress can be tracked through the entire journey. The robots are safe and secure, they can autonomously navigate obstacles and the onboard storage compartment can only be opened by the recipient with their smartphone app. Starship robots have traveled thousands of miles, interacted with millions of people, and have been tested in over 100 cities around the world. The company was founded in 2014 by Skype co-founders Ahti Heinla and Janus Friis. The current CEO is Lex Bayer, a former AirBnB executive.

Celluveyor: Manufactures a highly flexible modular conveying system with omnidirectional technology (cellular conveyor). Think of it as a multi-axis conveyor system.

CMC Machinery: The Italian firm produces a robot called CartonWrap, which recently partnered with Amazon. The robot packs boxes up to 5x faster than humans, and it is said that Amazon could replace up to 24 warehouse jobs with the machine with a payback period of a little over two years. The robot is capable of packing 700 boxes per hour. The machine requires a human operator to enter customer orders, another one to stock the cardboard and glue, and a technician to take care of any necessary repairs.

BrainCorp: A San Diego based tech company specializing in the development of intelligent autonomous navigation systems focused on developing advanced machine learning and computer vision systems for the next generation of self-driving robots. It is funded by Qualcomm ventures and Softbank Vision Fund.

Wing (owned by GOOG): Wing has developed and built a small, lightweight aircraft and navigation system which can deliver small packages including food, medicine, and household items. The drone has a payload of 3.3lbs and can travel up to 70mph. Its design is different than the typical drone as it looks more like a small plane - featuring two wings with propellers (14 in total including vertical propellers) that allow the drone to fly further while conserving energy. Once it reaches the customer's home, it hovers above, and a tether lowers the package to the customer (without actually landing). The company is currently working with Walgreens and FedEx to deliver small packages and has completed over 80,000 test flights.

Enabling Technologies For Warehouse Robots Of The Future

Advancement of the below technologies have been critical to allow for more material deployment of warehouse robotics. As the bots themselves become more ubiquitous pieces of hardware, the winners in the space will be those able to differentiate based on time to deploy, ability to integrate within larger IT systems, and downtime minimization, among others.

Cloud Robotics

Cloud Robotics is a field of robotics that integrates technologies such as cloud computing and cloud storage to benefit from the converged infrastructure and shared services for robotics. The high computational power of the cloud is essential for robot navigation, fleet management, monitoring, and analytics.

Advantages of the Cloud for Robots in the warehouse:

- More powerful computation, storage and communication resources. By offloading some of the processing and computing to the cloud, robots essentially just transfer the data and receive commands. This results in an order of magnitude reduction to what the robot needs to do.
- Avoid IT hurdles and increase security, these services are essentially outsourced. Real-time monitoring and trouble shooting.
- System agnostic, web-based applications on any device and any infrastructure.
- Deploy new sites more rapidly with easier scaling. Eliminates/reduces the need to upgrade IT infrastructure (such as installing servers) as robots use the cloud to operate.
- Collect, store, and analyze more data. This an important ingredient for Deep Learning capabilities.

Software

Most warehouses are managed using a software known as Warehouse Management Systems (WMS). This piece of software typically offers visibility and real-time data into a business' entire inventory and manages supply chain fulfillment operations from the distribution center to the store shelf. It is also tied to the company's ERP (Enterprise Resource Planning) software, where customer orders are typically handled and then communicated to the WMS. A good WMS software should make information flow seamlessly from the sales channel to order fulfillment, to packaging and finally shipping. As robots are deployed in warehouses, it is important that their software can be

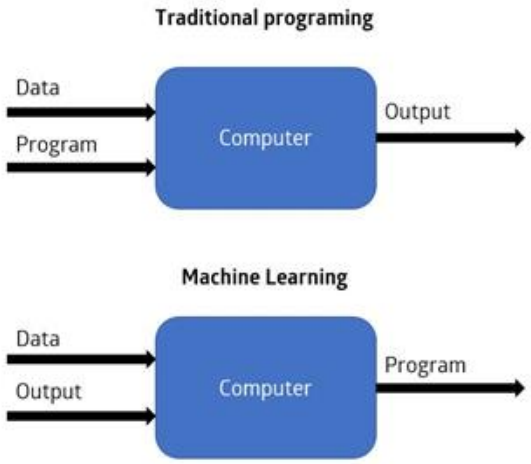
integrated with existing WMS in order to limit disruption and make deployments as seamless as possible. Most robot manufacturers offer compatibility with the most popular WMS packages.

Deep Learning

Deep learning is a subset of machine learning and part of the broader family of artificial intelligence. Deep learning allows for programs to solve specific tasks without being explicitly programmed to do so, but rather by *learning* through data and training via neural networks in order to come up with better outputs. It is more akin to how the human brain works (a neural network is a computer system modeled on the connections of the human brain). Deep learning is already being used in technologies such as facial recognition to unlock phones, identifying people in social media photos, and recommendation engines for streaming video and music.

Deep learning can consistently recognize anomalies and variance amongst a set of data, something that traditional computer systems based on rigid programming are not particularly good at. Deep learning is especially important for robot guidance, avoiding obstacles and mapping the warehouse.

Figure 42 Machine Learning Flow Chart Vs. Traditional Programming



Source: Cowen and Company

Machine Vision

Another key enabling technology in warehouse robotics, which is used in almost all types of robots. AMRs and Drones use different vision technologies (LiDAR, Cameras) to get around the warehouse and familiarize themselves with the environment (and in the case of drones deliver packages). Articulated Robots use machine vision to determine which packages to pick. Many robots require some machine vision system for object orientation, evaluation, and process execution. Conveyor systems use high-speed barcode readers and cameras that measure package sizes and spot anomalies and defects.

AMR Navigation Factors

There are several components that help robots understand where they are and navigate their surroundings safely. At the first annual Autonomous Mobile Robot Conference held in Louisville, KY in September 2019, Fetch Robotics CEO Melonee Wise gave a very helpful presentation that provided an overview of the basics of AMRs – part of the presentation focused on the various factors that robots must manage in order to traverse their surroundings safely and accurately, and included an overview of Odometry, Localization, Mapping, Navigation, and Obstacle Avoidance.

- **Odometry** – The use of data from moving sensors to estimate the change in position over time. Odometry is used by robots to estimate their position relative to a starting point. However, over time robots can accumulate errors that are caused by wheel slip, wheels shrinking over time due to usage, temperature changes, and other factors. To eliminate some of these errors, data from wheels and gyroscopes are combined using an Extended Kalman Filter (EKF) – while this doesn't eliminate errors, it produces values that tend to be more accurate. If a robot relies only on odometry, it will become lost over time due to slow accumulation of errors that are unavoidable.

- **Localization** – Determining where an object is with respect to a known map. Humans use street signs to navigate cities using maps. Robots use a similar process where laser scans are compared to a preloaded map - called scan matching. In dynamic work spaces that change a lot, there are not as many features for the robot to match against, which can cause it to become mislocalized.

- **Mapping** – Simultaneous localization and mapping (SLAM) is a technique used by robots to construct and update a map of an unknown environment while at the same time, keeping track of its location within the environment it is mapping. The robot drives around a warehouse and tries to match the laser scans together. The process is complex and as robots accumulate errors (from odometry) it can cause the map to overlap itself. This makes the mapping algorithm all the more important, because all mapping algorithms are different, and some do not function as well as others at scale.

- **Navigation** –Determining a path to a destination and then getting there, typically done by searching for a path across a grid. The path is typically filled in with obstacles from the map the robot has created, which are adjusted to account for the size of the robot and ensure it doesn't drive too close to objects.

- **Obstacle Avoidance** –Robots must also be able to avoid moving obstacles, and in order to do this, they track moving objects and project the expected future path so that a robot doesn't pull out in front of another robot, forklift or other piece of moving equipment. Having the ability to avoid objects, both moving and stationary, is the differentiating factor between AMRs and AGVs – AGVs have a preset path and have to stop and wait until the path is clear before proceeding, while AMRs can re-plan their path and avoid the obstacle.

Primer - Warehouse, Distribution, and Fulfillment Centers

What Is A Warehouse?

A warehouse is a building used for temporarily storing goods and is mainly used by manufacturers, import/exporters, wholesalers, retailers, and transport businesses. Typically, the buildings are tall and are located in industrial parks on the outskirts of a city or town. They have loading docks, pallets, storage racks, fork lifts, cranes, and involve significant manual labor. There are different types of warehouses, such as storage warehouses (i.e. traditional warehouses), distribution and fulfillment centers, retail warehouses, and cold storage warehouses.

What Is A Distribution Center?

A distribution center (DC) is a type of warehouse where finished goods are stored and shipped to retailers, wholesalers, and customers. The traditional warehouse is used for storing finished goods for longer periods of time, while a distribution center, apart from storing, can offer other services such as product mixing, shipment cross docking, and packaging. As a result, a DC will store products for a shorter period compared to a warehouse, meaning the flow velocity is much greater in a DC vs. a traditional warehouse. A DC is more customer centric, connects suppliers and customers (B2B and B2C), and normally ships in bulk. Finally, the operations of a DC are much more complex than a warehouse, and as a result require better use of technology for order processing, fulfilment, warehouse and transportation management, etc. Walmart is known for its revolutionary use of company-owned Distribution Centers which helped it expand for decades by managing their own inventory in a closed network and increase turnover.

What Is A Fulfillment Center?

A fulfillment center (FC) is in many ways like a DC, but it is even more specialized in the sense that it provides additional services, such as product finishing and mixing, packaging, taking customer orders directly, providing customer support, and managing returns. Another difference is that orders are typically going out straight to the customer's premise instead of a retailer, therefore shipments are smaller and more individualized. It is more expensive than a distribution center given the additional services it provides. The Amazon Third-Party market place, also known as Fulfilled by Amazon, is an example of this service.

What Is A Sortation Center?

In the past few years, Amazon has started opening "sortation centers" to tackle the last-mile delivery challenge (the most expensive part of a delivery). These differ from distribution centers in two ways: they are much smaller (usually about 1/3 the size of an FC) and there are no visible products, only packages. These packages get sorted and then leave to either the customer's location or to the closest local post office. Amazon's intention is to get as close to the customer as possible to cut-down delivery times.

Figure 43 Warehouse Matrix

Warehouse type	Users	Specialized?	Level of automation	Size
Traditional warehouse	Retailers, logistics, transport, manufacturing supply chain	No	Low Forklifts, RFID tags	Hundreds of thousands sq. ft.
Distribution center	Retailers	Yes	Medium AGVs, conveyor belts	Hundreds of thousands to millions of sq. ft.
Fulfillment center	E-commerce	Yes	High AMRs, machine vision	Up to a Million sq. ft.
Sortation center	E-commerce	Yes	High AMRs, machine vision, conveyor belts	Hundreds of thousands sq. ft. (one third the size of an FC)

Source: Cowen and Company

The Warehouse: Yesterday, Today, And Tomorrow

The simple rule in traditional supply chains was to store the *maximum possible quantity of every product, everywhere, and every time*. The new supply chain rule is to have *the required quantity of the right product in the right place at the right time*.

With the rise of eCommerce, warehouse capabilities are being adjusted to the new norm and as a result redevelopments and new construction are expected to accelerate. According to CBRE, the average U.S. warehouse is 34 years old. The typical old warehouse had different dimensions and different features such as lower ceilings (24 feet then vs 40 feet today), less load bays, uneven floor space, and inadequate docking. Logistically and physically, a warehouse designed for customer on-premise delivery is not the same as one designed for bulk shipping into stores. For example, an Amazon warehouse will differ greatly from a Walmart warehouse as one is expected to provide anywhere from 2 day to 2-hour shipping on millions of SKUs to thousands of addresses, while the other might ship the same selection of items in bulk once a day to nearby stores. This is one reason why Walmart has struggled to catch up with Amazon in online sales: their logistics network is much more centered around Distribution Centers whereas Amazon has built mostly Fulfillment Centers specifically tailored for eCommerce.

The shift from the old-warehouse model to the future warehouse model is a migration away from warehouse-based stockpiling of inventory to high-velocity operations pushing more products through the same fixed assets while bringing down overall costs. This also means that distribution and fulfillment centers have become a strategic facility in many cases providing a competitive advantage, as opposed to purely a cost center as a traditional warehouse would be thought of historically.

Warehouse Tasks

The three main warehouse tasks have been traditionally very tedious, manual processes: picking, moving, and packaging.

Picking: Picking is the centerpiece of eCommerce order fulfillment. It involves the task that moves products from sitting on a shelf in a warehouse to the pre-delivery stage. The picker selects items from storage and prepares them for shipment. Duties include reading the digital order request, pulling the item, and placing it in the correct box or container for the order packers. Manual item picking is a labor-intensive and tedious task and can consume as much as half of a logistics provider's operational costs. Workers move around the warehouse to find the items that have been placed on order and prepare them for pre-delivery and packaging.

Moving: Warehouse workers in a typical facility can walk as much as 10-20 miles a day, which may add up to more than 50% of their time spent picking orders. Mobile robots move more quickly than a human typically does, although there are safety routines built into the software to slow a robot down when nearing congestion, as well as to come to a complete stop rather than running into a human or non-human obstruction. It also frees up time for workers to focus on other tasks.

Packaging: The last stage before the delivery goes out is putting the item or items in a box and assembling packaging, label, and recording what is being packed. The packager will also inspect all the materials inside and make sure there are no tears, cracks, or dents in the final package.

How Warehouses Have Historically Used Automation

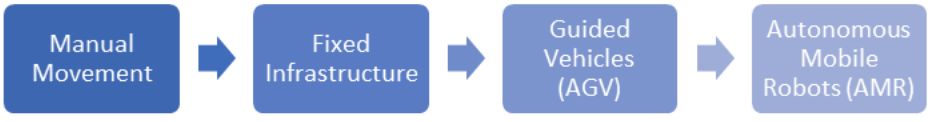
Warehouse operators have recognized the importance of automating tasks in the past, and there are various technologies already in place that have helped them achieve this.

Conveyor belt systems are a common piece of mechanical handling equipment used to move materials from one place to another. In warehouses they typically transport bins, totes, and packages. Their main disadvantages are that they are fixed which makes them inflexible, and if there is a bottleneck at any single point the whole system must be stopped.

Pick-to-light/pick-to-voice: Pick to light is an order-fulfillment technology designed to improve picking accuracy by using alphanumeric displays in storage locations to guide employees in picking, putting, sorting, and assembling. Pick-to-voice is similar but instead uses voice prompts from a voice-picking device the worker wears to free up their eyes and hands.

AS/RS: Automated storage and retrieval system is a computer-controlled, fixed track system for automatically placing and retrieving loads from a defined storage location.

Figure 44 Evolution Of Warehouse Automation



Source: Cowen and Company

Order Fulfillment Systems

Person to Goods (P2G): Considered the traditional manual process of fulfilling orders in a warehouse where the warehouse worker walks to the station where the orders are stored and picks the order there, usually the path is determined using guiding technology such as RF, voice and or light directed technologies to guide the picker's activities. Advances such as smart carts (like 6 River's Chuck) can improve this process by moving with the worker to help identify and streamline the product location, quantity, etc.

Goods to Person (G2P) An automated warehouse sortation system (such as an AGV or AS/RS) that brings the goods or order to the warehouse worker who sits in a workstation or remains in a specific area. This can be carrying a rack with multiple SKUs, for example, and the worker can then select the specific product and prepare it for packaging.

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