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Weekend Tech Byte: Talk to the Hand (One Year Later)

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By Alberto Moel

One year and five days ago (***Weekend Tech Byte: Talk to the Hand***) we wrote a *Weekend Tech Byte* that summarized the state of the art in automated warehouse logistics and bin picking. At the time we made the bold prediction that although state of the art was, ahem, *lacking*, it was going to evolve quite rapidly.

And rapidly it did evolve. As we review in this week's note, progress in automation for both warehouse logistics and bin picking has been notable and faster than we expected.

What happened to drive this progress? Very simply:

+ The 2015 Amazon Picking Challenge (APC), which we described in detail last year (***amazonpickingchallenge.org***), was a catalyst to get researchers and engineers all excited about the opportunity of cracking the bin-picking problem, and showing off in the 2016 APC. This is analogous to the 2004 DARPA Grand Challenge on autonomous vehicles driving (excuse the pun) researchers and engineers to crack the autonomous vehicle technology a few years later;
+ In March 2012, Amazon acquired Kiva Systems for a reputed $775 million. Kiva Systems, which had developed an automated warehouse logistics system, was being rolled out rapidly to blue-chip clients such as Staples, Walgreens, and Gap until it was acquired by Amazon and went stealth-silent. Amazon's tight-lipped stance and the economic benefit of automated fulfilment means that the vacuum left by Amazon's taking all of its marbles and going home was going to be filled by many other entrepreneurs;
+ And (somewhat to our surprise) machine learning and artificial intelligence (*les buzzwords du jour*) have had an impact on the capability of both the bin picking and warehouse logistics technologies. We had written about it, more on a speculative basis (***Weekend Tech Byte: Taking the Human Out of the Loop (Homage to Alan Turing)***), but it seems there is a seriousness about this that was unexpected.

So onwards and forwards with an update on what's happened in the last year for us to revisit this *Talk to the Hand* stuff. We'll talk about progress in all of these areas, and more. But first, a victory lap to honor the effort of the hundreds of engineers and scientists pushing technology forward, and for prescience (read "luck") in our forecast (Exhibit 1).

EXHIBIT 1: **Victory Lap: The obligatory humorous and only marginally-related first exhibit in a Weekend Tech Byte sourced from Wikimedia Commons to avoid issues with copyright**

Source: Wikimedia Commons

THE 2015 AMAZON PICKING CHALLENGE: SHOULD HAVE STAYED HOME INSTEAD

When it comes to work in the physical world, humans still have a huge flexibility advantage over machines. Automating a single activity, like soldering a wire onto a circuit board, fastening two parts together with screws, or picking an item out of a bin is pretty easy, but that task must remain constant over time and take place in a consistent environment. The circuit board must show up in exactly the same orientation every time, the item to be picked from the bin aligned precisely, of a certain geometric form factor, and tagged so it can be identified by the machine.

Each time the task changes – each time the location of the screw holes move, or the orientation of an item changes, for example – production must stop until the machinery is reprogrammed. Today's factories, especially large ones in high-wage countries, are highly automated, but they're not full of general-purpose flexible automated systems. They're full of dedicated, specialized machinery that's expensive to buy, configure, and reconfigure.

As the eminent roboticist Rodney Brooks likes to note, roboticists have been successful in designing robots and automation systems capable of super human speed and precision. What's proven more difficult is inventing robots that can act as we do – in other words, that are able to inherently understand and adapt to their environments.

This reality is also known as *Moravec's paradox* (after CMU robot expert Hans Moravec) –"it is comparatively easy to make computers exhibit adult-level performance on intelligence tests or playing checkers, and difficult or impossible to give them the skills of a one-year-old when it comes to perception and mobility."

This pesky ability of humans to outperform machines in simple tasks like picking stuff out of a bin is at the core of solving one of the more vexing problems in automation – the fully-automated fulfilment center. But first, a gratuitous (but necessary) diversion into what the heck is a fulfilment center.

The fulfilment (or distribution) center, with irrelevant pictures

Whenever you buy something from Amazon, Staples, The Gap, or any one of (what it feels like) millions of online retailers, the stuff has to eventually get to you, and that's no easy task.

Let's say you've ordered (in a single order) from Tyler Brûlé's specially-curated Monocle online store (Twee.com) a Williams Sonoma acorn twine holder[1], a Jacques Pépin cookbook, and a dozen Pillsbury cinnamon rolls, and you live in East Chicken Switch, Texas.

Your order goes up into the cloud[2] and passes through multiple electronic switches until it arrives at the physical switch represented by Twee.com's fulfilment center in Kerrville, Texas, which is nearest to your home.[3] You can really imagine the fulfilment center as a giant physical switch (Exhibit 2), breaking up packets of stuff and recombining them into packets containing other stuff.

EXHIBIT 2: **A Network Switch: Another gratuitous and relatively irrelevant representation of what we're trying to say, but free of copyright issues**

Source: Wikimedia Commons

At one end of the center are trucks full of boxes ("packets") with acorn twine holders, Jacques Pépin cookbooks, and Pillsbury cinnamon rolls. These boxes are unloaded by possibly disgruntled humans[4], opened up, dumped on the floor, sorted, and assigned a location in a shelf somewhere in a cavernous and unpleasant 120,000 square foot warehouse.

At the other end of the center are more possibly disgruntled humans, who receive your order from the cloud, walk to the different physical locations where your three items are stored, and put them in a separate box ("packet"), seal it up, and send it off to more trucks for the "last mile" delivery to your home. They do this over and over, eight hours a day, five days a week, with overtime for holidays and peak periods.[5]

A typical warehouse holds several million different products with thousands and thousands of shapes, sizes, and materials. Neither the product mix nor its packaging is stationary, and changes regularly and seasonally. The human operator has to consistently identify and pick an irregularly-shaped (and irregularly placed) object out of the shelf in an error-free way.

We estimate that 70% to 80% of the worker's time is devoted to picking and packing. And 60% to 70% of a worker's day is spent walking among the shelves. In other words, about half of what a company is paying for is time spent walking. Even at $2 an hour it adds up if distribution margins are low.

[1] Yes, Virginia, there is such a thing: http://www.williams-sonoma.com/products/acorn-twine-holder/ .

[2] Shorthand for "somebody else's insecure computers."

[3] Why Kerrville, Texas? Because that's where Kinky Friedman (https://en.wikipedia.org/wiki/Kinky_Friedman) lives. Enough said.

[4] Evidence for this are comments from fulfilment center operators that labor turnover is 100% a year.

[5] No wonder they are generally disgruntled and turnover is 100% a year. Definitely worse than the SSDD of a sell-side analyst.

Step 1: Automating all the walking around

This nasty business of the fulfilment center screams for automation. The low hanging fruit, from a cost and technology perspective, is automating all the walking around. And indeed, we find that many of the simpler logistics and material handling operations are now being rapidly automated.

The canonical example of this (followed by its many imitators and competitors, naturally), is ***Kiva Systems***, which automated fulfilment centers. In a land grab of momentous proportions, Amazon acquired Kiva Systems in March 2012, for a reported $775 million. After the usual gnashing of teeth and rending of clothes that follow an acquisition (plus the defection of key talent), the company was renamed Amazon Robotics.[6]

The simple idea behind the Kiva system is that Items are stored on portable shelves. When an order is being filled, software locates the item in the warehouse and dispatches a robot (inauspiciously shaped like a square, wheeled cockroach) to line up under the shelf, lift it, and bring it to the fulfilment station for the human operator to pick the items. After picking, the robot takes the shelf back to a location on the floor.

A typical bin on a shelf will have up to 10 items in it, and the human operator is able to identify the right product, pick it out of the bin, scan it, and put the item in a box, all in only a few seconds.

The algorithm for shelf fetching and returning also optimizes the distance between the shelf and the fulfilment station so as to place shelves with "popular" items closer to the fulfilment stations as they are likely to be picked more frequently.

We have not run the detailed economics of the Kiva system, but we estimate a typical120,000 square feet of space would require about 200 Kiva robots and 5,000 movable shelves, with 20 picking stations.

Assuming shelves are about $1,000 each and robots $30,000 each, a Kiva installation would cost about $12 million to put together ($6 million in robots, $5 million in shelves, and $1 million in integration costs).

The 20 picking stations would have 20 humans, each earning $12 per hour (including benefits), two shifts a day, 250 days a year, or about $1 million in wages per year.[7]

Making some simple assumptions about the improved efficiency of the human operator (who no longer has to walk all over the warehouse looking for stuff and can probably fill 4-5x as many orders as before), a Kiva system would pay for itself in 2-3 years, which is not a bad return on investment.

Step 2: Automating the bin picking, take 1: Road Trip![8]

Although the automation of goods motion and placement at the picking station is an "easy" one, the automation of the actual picking step by human hands is an *incredibly hard* problem.

Amazon, in its infinite wisdom, is fully aware of this quandary, and sponsored the *2015 Amazon Picking Challenge*[9] in its hometown of Seattle at the 2015 ICRA conference.[10] The basic idea from Amazon was to spur innovation and development in automating picking, as that remained the major roadblock to the complete automation of its fulfilment warehouses.

The rules of the 2015 Amazon Picking Challenge were based on a simplified version of the picking task. Each team was provided with a Kiva shelf consisting of 12 cubbyholes holding 25 items of various sizes and weights, such as books, cat treats, and cookies.

The objects were placed randomly in the cubbyholes, and each team had a different configuration of 12 objects and positions to pick, in twenty minutes.

26 teams from the finest academic and industrial robotics centers from all over the world rose to the challenge, and were given financial and technical support by Amazon and the other sponsors, including Rethink Robotics, Yaskawa, Fanuc, and Universal Robots.

Contestants were allowed to use any type of robot, imaging system, and manipulator, but once given the list of items to pick; the system must be autonomous and not rely at all on human direction.

The contestants were scored based on how many of the specified subset of items they pick within a specified time. Contestants lost points for picking the wrong items, dropping items, or breaking items. The top three contestants shared a prize pot of $26,000, with $20,000 going to the top scorer and $5,000 to the next.

The teams used an assortment of sensing, motion control, and manipulation technologies during the event: ABB robots, Rethink's Baxters, Yaskawa Motomans, PR2s, Barrett arms, UR arms, and Rube Goldberg homemade contraptions; LIDAR lasers[11], three-fingered robotic arms, scoops, hands, grippers, tape measures that function as a tongue-like grasper, and several types of suction mechanisms.

End effectors were made or covered in a range of materials – wood, metal, plastic, soft silicon, and other unidentified substances (Exhibit 3).

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[6] *www.amazonrobotics.com* . The aforementioned key talent that defected is now at companies developing competing approaches to Kiva Systems. We'll have more to say about that later in this note.

[7] Not including turnover, training costs, and overtime, so this $1 million number is likely a lower estimate.

[8] https://www.youtube.com/watch?v=Nzg9cE7-2LQ

[9] *http://amazonpickingchallenge.org/*

[10] *http://www.icra2015.org/*

[11] LIDAR ("LIght Detection And Ranging") is a sensing technology that can image objects by illuminating the target with a laser and analyzing the reflected light.

The challenge combined object recognition, pose recognition, grasp planning, compliant manipulation, motion planning, task planning, task execution, and error detection and recovery. Trivial for even a modestly-capable human, but how about for a machine?

EXHIBIT 3: **Rube Goldberg at work**

Source: Photograph by author

Team RBO from TU Berlin won the challenge by successfully picking 10 out of 12 objects in a 20-minute period, with Team MIT in second place, picking up 7 items correctly. 13 of the 26 teams picked *nothing* from their shelves (Exhibit 4).

Not exactly an inspiring performance, considering that each team consisted of some of the brightest minds in robotics from the finest universities and research centers, with ample resources and time (graduate students, engineers, and scientists), as the teams had been developing their systems for the 5-6 months previous to the contest in late May 2015 (Exhibit 5).

In the end, their collective millions of dollars of investment and brainpower couldn't beat a five-year-old's grubby hand and pink-eyed eye at a simple-minded task that would take the human combo 5 minutes to complete.

As Andra Keay from *Robohub* eloquently put it, "*it was like watching paint dry… As a spectator, I spent most of my time watching robots do nothing. Large amounts of nothing. Occasionally nothing would be enlivened by an attempt to pick up nothing, or perhaps the shelf itself. Once or twice I saw a real pick get dropped.*[12]

Quantitatively, how bad was it? According to Amazon, a human is capable of performing a still more complex version of the 2015 APC bin picking task at a rate of about 400 picks per hour with under 1% error rate. For comparison, the best robot in the 2015 APC achieved a rate of about 30 picks per hour with a 16% failure rate. Over10x slower than a human and orders of magnitude lower in accuracy. Not exactly worthy of a year-end bonus, it seems.

So what do you do when your road trip turns into a fiasco featuring Otis Day and the Knights?[13] Of course, you try again! Cue the *2016 Amazon Picking Challenge.*

EXHIBIT 4: **2015 APC Results: Kind of a bust...**

Team	Score	Correct	Wrong	Drops
RBO	148	10	1	0
MIT	88	7	0	0
Grizzly	35	3	1	2
NUS Smart Hand	32	2	0	0
Z.U.N.	23	1	0	0
C^{2}M (Mitsubishi)	21	2	1	0
Rutgers U. Pracsys	17	1	0	1
Team K	15	4	3	1
Team Nanyang	11	1	0	0
Team A.R.	11	1	0	0
Georgia Tech	10	1	0	0
Team Duke	10	1	0	0
KHT/CVAP	9	2	1	0

Source: Amazon Robotics

EXHIBIT 5: **...and not for lack of trying or resources**

Team	Platform	Gripper	Sensor
RBO	Single arm (Barrett) + Nomadics XR4000 platform	Suction	Multiple 3D imagers
MIT	Single arm (ABB 1600ID)	Suction + gripper + spatula	2D and 3D imaging
Grizzly	Dual arm (Rethink Baxter) + mobile base	Suction and gripper	2D and 3D imaging
NUS Smart Hand	Single arm (Kinova)	Two-finger gripper	3D imaging
Z.U.N.	Dual arm (Custom)	Suction	N/A
C^{2}M (Mitsubishi)	Single arm (MELFA) on custom gantry	Custom gripper	3D imaging
Rutgers U. Pracsys	Dual arm (Yaskawa Motoman)	Vacuum + Robotiq 3-finger hand	3D imaging
Team K	Dual arm (Rethink Baxter)	Suction	3D imaging
Team Nanyang	Single arm (UR5)	Suction and gripper	3D imaging
Team A.R.	Single arm (UR10)	Suction	3D imaging
Georgia Tech	Single arm	SCHUNK 3-finger hand	3D imaging
Team Duke	Dual arm (Rethink Baxter)	Righthand 3-finger hand	3D imaging
KHT/CVAP	Dual arm + Willow Garage PR2 mobile base	PR2 2-finger gripper	2D/3D imaging and lasers

Source: Amazon Robotics, Bernstein analysis

[12] Here you can see the winning Team RBO at 4x speed. Indeed, like watching paint dry: *www.youtube.com/watch?v=LtWPH-bcc4M*

[13] *https://www.youtube.com/watch?v=g7IR3YDzKCA*

THE 2016 AMAZON PICKING CHALLENGE: PROGRESS!

The 2016 APC was held in Leipzig, Germany, at the end of July as part of the 2016 RoboCup contest.[14] Again, teams from around the world were invited to participate, but this year Amazon upped the ante, making the exercise much more difficult (and realistic):

+ Bin picking (the **Pick Task)** was made more difficult for the 2016 APC. Although the task still involved picking 12 items, each shelf included 50 items, instead of 25, with items more densely-packed or occluded. Additionally, the picking time was cut from 20 minutes to 15. Dropping things, or even nudging them so that the item stuck out more than 0.5" from the shelf resulted in penalties.

+ The 2016 APC deliberately included a few items that were unsuitable for suction picking, including a wire trash can and a heavy dumbbell. Therefore, all teams had to resort to multiple gripping approaches beyond suction.

+ Further, a **Stow Task** was added, which consisted of moving 12 target items from a tote into bins on the shelf. The items on the tote were arranged so that some items were partially or completely occluded below other items.

This time around, only 16 teams stepped into the ring, even if Amazon sweetened the pot to $50,000 for first prize. The winner of the overall competition was Team Delft, a partnership between researchers from the TU Delft Robotics Institute and the company Delft Robotics in The Netherlands. Team Delft won both the Pick Task (Exhibit 6) and the Stow Task (Exhibit 7), with NimbRo Picking of Bonn University, PFN-Fanuc of Japan, and MIT rounding out the top four slots in both contests. For the Pick Task, Team Delft and were tied on points, and the tie-breaker was decided on which team was faster on first pick.

EXHIBIT 6: **2016 APC Pick Task Rankings**

Team Name	Score
Team Delft	105 (0:30 first pick)
PFN-Fanuc	105 (1:07 first pick)
NimbRo Picking	97
MIT	67
Team K	49
ACRV	42
CMU-HARP	33
C^2M	21
Dataspeed-Grizzly	21
AA-Team	16
IITK-TCS	16
Applied Robotics	10
Duke	0
KTH	0
microRecycler	0
Rutgers ARM	N/A

Source: Amazon Robotics

EXHIBIT 7: **2016 Stow Task Rankings**

Team Name	Score
Team Delft	214
NimbRo Picking	186
MIT	164
PFN-Fanuc	161
IITK-TCS	109
HARP	88
Duke	66
Team K	52
KTH	40
microRecycler	20
C^2M (Mitsubishi)	16
Applied Robotics	15
AA-Team	3
ACRV	0

Source: Amazon Robotics

What can we point to as progress in the 2016 APC relative to 2015? We see three areas where material advances have occurred, which have relevance to investors: ***systems performance***, the increasing use of ***machine learning***, and ***corporate participation.***

Improvements in systems performance

The Team Delft robot managed to pick items at a rate of about 100 an hour, with a failure rate of 16.7%. Although the failure rate did not see much improvement from the 2015 APC, the pick rate more than tripled from 30 items an hour. Still not quite human levels of 400 picks an hour with minimal failure, but excellent progress nonetheless.

More importantly, there was material improvement in the aggregate capabilities. Although the Pick Task was much harder in 2016 than in 2015, only four teams failed to score any points at all, compared to 2015, when 13 teams scored a donut. Six of the teams in 2016 also managed to score more than 40 points, which would have been enough to earn them third place in 2015.

A successful picking solution needs to overcome *perception*, *manipulation*, and *integration* problems, and the progress seen in solving the bin picking puzzle is outstanding.

Solving the perception problem. It's conceptually very easy for a camera to capture a 2D or 3D image and do some simple processing as to what it's "seeing". It's a lot trickier when the objects to be identified are scattered haphazardly in the vision field, or possibly occluded by other objects.

Many companies are heavily involved in solving this 3D perception problem. One approach is to use LIDAR lasers, which have been developed by companies such as ***Hokuyo***[15] and ***SICK***.[16] Other approaches use traditional digitization approaches together with sophisticated 3D imaging, such as those pioneered

[14] http://www.robocup2016.org/en/about/robocup-2016/

[15] www.hokuyo-aut.jp

[16] www.sick.com

by ***Cognex***[17], ***Universal Robotic***'s Neocortex Vision System[18], ***Microsoft***'s Kinect[19], and ***Intel***'s RealSense[20] cameras.

Solving the manipulation problem. Once the object has been successfully identified, it needs to be picked and put in a bin. The human hand, with thousands of sensing points, multiple degrees of freedom, and its fine motor feedback, is ideal for this task.

For that reason, many of the leading edge robotic manipulator companies have focused on developing "hands" with similar mechanical and sensing capabilities as the human hand. Barrett Technology's WAM Arm[21] is designed in the shape of a human hand and uses unique cable tensioners to provide force feedback the same way a human hand does. Weiss Robotics' tactile sensing hands[22] are covered in pressure sensors that mimic the human hand's physical feedback. But many other alternative manipulation approaches are being tried out. Simplified grasping tools using two fingers or suction cups are most popular.

Solving the integration problem. The human brain is a wonderful thing. It takes the data from the perception module (the eyes), processes it superbly, and then signals to the manipulation module (the hand) to act on a particular object, no matter how it's positioned, what is its shape, or whether is not completely visible.

This is primarily a "software" problem, but it's a *hard* software problem. The human brain has the advantage of a massive "database" of objects it has been learning about for years before that brain becomes an Amazon picking station operator.

Replicating that using inorganic hardware is not trivial, but work continues by many of the deep learning and machine vision companies out there[23] plus many, many other startups such as Capsen Robotics[24], and my favorite, Japan's Preferred Networks (PFN), second-place photo-finisher in the Pick Task at the 2016 APC.[25]

The increasing use of machine learning

Team Delft trained its system to recognize the 40 Amazon warehouse items by feeding into a deep learning system a database of 3D scans of the items. High quality 3D cameras captured images of the objects to be picked, which were then fed to the deep learning system for identification.

A custom gripper and suction arm attached to an off-the-shelf seven degree of freedom Yaskawa arm did the dirty work of picking the items. Using machine learning, the robot demonstrated the ability to work in an uncontrolled environment such as a warehouse.

Similarly, second-place photo-finisher PFN-Fanuc used state-of-the-art deep learning algorithms and Chainer, a Python-based open source deep learning framework on input data obtained from image and 3D location sensors.

The sensors and machine learning software were coupled to two M-10iA Fanuc robots equipped with in-house specialized end effectors to reliably grab the items. Expertise in machine learning enabled PFN to build a system that can compete with the world's leading robotics institutions in only three months.

We don't think it's a coincidence that the first and second place finishers in the 2016 APC were using some form of machine learning in their systems. We had previously postulated this was going to happen (***Weekend Tech Byte: Taking the Human Out of the Loop (Homage to Alan Turing)***) and it is surprising the level of progress seen in just a few months in this area.

Increasing corporate participation

Compared to 2015 APC, when none of the competitors were purely corporate, and only three were corporate-academic collaborations, the 2016 APC saw the first and second place finishers having a corporate relationship – Team Delft with Delft Robotics, and PFN-Fanuc, a collaboration between PFN and Fanuc. This is encouraging as the technology migrates from university "science fair" projects to real-world applications.

Incidentally, the PFN-Fanuc project is more than just the 2016 APC project and the integration of machine learning into factory automation. Besides Fanuc owning 6% of PFN, the collaboration is also part of Fanuc's recently announced FIELD system[26] – intelligent middleware that connects factory-floor systems (e.g. robots and CNCs) to each other in a seamless way.

The FIELD system will interface with Fanuc's Link-i and ZDT applications as a way to integrate Fanuc's archipelago network protocols into something more usable, as the move to open standards (e.g. EtherCAT by Beckhoff) continue to grow. We wrote about this in our recent write-up of the automation tour (***Global Automation: Key Findings from the Automation for the People 2016 Asia Tour***).

FIELD also provides an interface to Rockwell's FactoryTalk View, FactoryTalk Vantage Point, and FactoryTalk Production Center, which extends Rockwell's capability with Fanuc's products. Not coincidentally, Fanuc's own factories are controlled by Rockwell FactoryTalk's systems. It looks like an "easy" win by taking all the development effort Rockwell and Fanuc put together in Fanuc's own factories to offer it to 3rd parties.

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[17] ***www.cognex.com***
[18] ***http://www.universalrobotics.com/neocortex***
[19] ***https://www.microsoft.com/en-us/kinectforwindows/***
[20] ***http://www.intel.com/content/www/us/en/architecture-and-technology/realsense-overview.html***
[21] ***www.barrett.com***
[22] ***www.weiss-robotics.com***
[23] ***Weekend Media Blast: Playing Where The Puck is Going To Be – Three Technologies That May Change The World***, and ***Weekend Media Blast: AI, Machine Learning, and Deep Learning vs. Isaac Newton***
[24] ***www.capsenrobotics.com***
[25] ***https://www.preferred-networks.jp/en***.
[26] ***http://www.fanucamerica.com/FanucAmerica-news/Press-releases/PressReleaseDetails.aspx?id=79***

WAREHOUSE LOGISTICS AUTOMATION UPDATE: ONWARDS AND FORWARDS!

As the share of commerce occurring online increases, the need for speedy and reliable fulfilment is exploding. However, both the legacy "low tech" approach to warehouse operations (humans all over the place), or the legacy "high tech" one (fixed automation and AGVs following clearly marked paths in human-free areas) are becoming obsolete.

At the same time, companies put off investing in material handling equipment for their warehouses during the financial crisis, and now have to invest to catch up. Luckily for them, the last few years have seen some incredible progress in mobility, vision, and software that permit this kind of a changeover without having to build new facilities.

About half the human labor in warehouses spends its time walking and another 30% moving stuff around – unpacking incoming goods, restocking shelves, filling orders. Basically menial, thankless activities. According to the US Bureau of Labor Statistics, there were 856,000 fulfilment warehouse workers in the US in May 2016, and the average wage is $12 per hour.

High employee turnover (100% in some cases), looming wage hikes in locations close to city centers (needed for same-day delivery), tight labor markets around peak seasons, and disgruntled employees; coupled with the rapidly declining cost and increasing flexibility of automation (***The Long View: Automation for the People***) has led warehouse operators to actively experiment and deploy automation solutions.

We did write about this in our *Weekend Tech Byte* of a year and five days ago (***Weekend Tech Byte: Talk to the Hand***), but an update is in order on what has evolved since then (and evolved it has). In particular, we'd like to highlight two companies not featured previously that we think have some interesting technology worth watching – Locus Robotics[27] and IAM Robotics.[28]

Locus Robotics – Necessity is the mother of reinvention

Locus Robotics is a spinoff of Quiet Logistics, a third-party logistics provider in Western Massachusetts, focusing primarily on apparel distribution for brands such as Zara, Gilt, and Bonobos.

Quiet Logistics itself is an interesting story. Quiet was launched in early 2009 by Bruce Welty, a seasoned entrepreneur in warehouse logistics software. Welty's insight was to use Kiva Systems' robotic solution as the linchpin of a third-party logistics business. Business was doing great until 2012, when Amazon bought Kiva and left Quiet loudly in the lurch, with no upgrade path, and limited maintenance and support.

[27] ***http://www.locusrobotics.com/***
[28] ***https://www.iamrobotics.com/about***

So Welty and his team doubled down and in early 2014 started Locus Robotics as a next-generation alternative to Kiva's now rapidly obsolescing and hard-to-maintain solution.

Locus' robots operate differently from the Kiva Systems approach. Rather than bring the merchandise pod to the picking station, the Locus robots head to the item to be picked and prompt humans to load a bin at the robot's base. The robots then move on to the next location for items to be picked. The human workers are each in charge of a small zone, so walking distances are much shorter.

Because technology has evolved since Kiva Systems (which are, let's face it, an early-2000's technology incarnation, in much the same way the 1980s Space Shuttles used 1970s technology), the Locus robots are much smarter and efficient. The robots are autonomous and do not require fiducial grids, a pristine level floor, or special shelving to operate. Locus also uses fewer robots per square foot of warehouse space, needing 5-7 robots per 10,000 square foot of space, half as many as a Kiva system.

And most importantly, the robots have some level of awareness, with 3D time-of-flight cameras from IFM[29] and LIDAR that allows the robot to map the surrounding space and identify humans and other obstacles. Unlike Kiva robots, which cannot operate safely around humans, the offering from Locus is collaborative.

Locus Robotics claims efficiency about twice that of the Kiva Systems at a competitive cost, and the investment proposition allowed it to raise $8 million in venture capital funding in May 2016. Locus has no outside customers right now (except its own Quiet Logistics parent warehouses), but pilot programs are expected later this year.

IAM Robotics – the great is the enemy of the good enough

IAM Robotics of Pittsburgh was founded in 2012 by CMU scientists and engineers to take a crack at the picking problem. IAM developed Swift, an autonomous mobile picking robot which has a wheeled base and a 15lb payload Fanuc robot arm with a suction gripper.

Instead of solving the general picking problem of Amazon's concern, IAM has focused on a narrow subset of items already in clearly-defined packaging and amenable to suction picking – bottles, boxes, and pharmaceuticals.

The IAM system uses a portable scanning system called Flash to pre-identify the different SKUs in a warehouse, which are then fed to the robot to identify items to be picked. Because of the reduced nature of the picking problem, an IAM system can be more than twice as fast as an expert human picker.

IAM is currently trialing their system for pharmaceuticals fulfilment at the Rochester Drug Cooperative, where the packaging types and number of SKUs are bounded and clearly classified.

[29] ***www.ifm.com***

We have identified many other efforts in general warehouse automation, some of them more likely to succeed than others:

+ ***Fetch Robotics*** (Exhibit 8) introduced a system consisting of a mobile base (called Freight) and a robot arm (called Fetch). The robots are designed to work alongside workers performing tasks such as goods delivery, and pick and pack.[30]

+ ***Magazino*** from Germany has developed TORU, a columnar robot with a gripper system capable of removing a single item. The system is able to grab a rectangular object, put it in its built-in shelf and deliver it to a picking station.[31]

+ A parallel approach to warehouse automation comes from ***Symbotic***, of Wilmington, Massachusetts. Symbotic is majority owned by C&S Wholesale Grocers and focuses on grocery fulfillment. Their system consists of squat robots that grab closed boxes of merchandise and deliver them to another (third party) robot that puts them on pallets for trucking.[32]

+ ***Adept Robotics*** (now owned by Japan's Omron) has developed a series of high-payload autonomous mobile transporters for logistics, warehouses, and manufacturing.[33]

+ ***Swisslog*** (96% owned by KUKA) developed the CarryPick system which uses automated guided vehicles (AGVs) and mobile racks. Instead of raising the racks from below as Kiva does, the CarryPick system lifts them from above.[34]

+ ***Autostore*** from Norway's Hatteland, uses a compact grid with robots that ride on top of the grid shelving items for storage.[35]

+ ***Grenzebach***, a private company which used to own 25% of Swisslog and 25% of KUKA itself, has developed the Carry AGV, which can autonomously transport heavy cargo in a warehouse.[36]

+ ***C&D Skilled Robotics*** of Texas (owned by Italy's Euroimpianti since 2008) specializes in AGVs, automatic truck loaders, and palletizing systems for warehouses.[37]

+ ***Grey Orange***, an Indian firm, is developing the Butler System, a mobile robot which picks up and moves portable shelves.[38] ***Hi-tech Robotic Systemz***, an Indian robotic systems integrator has also shown a fulfilment AGV.[39]

+ Another approach is robotic gantries, for example ***CIMCORP*** based in Finland, but owned by Murata of Japan.[40] The CIMCORP system creates stacks of goods from the receiving dock. When a particular SKU is required to fulfill an order, a robot retrieves the corresponding bin which is gantried to the picking stations. ***Vanderlande***[41] from The Netherlands, ***Bastian Solutions***[42] from the US, and ***Dematic GmbH***[43] from Germany (but acquired by China-controlled KION Group in June) have similar systems.

+ In the "interesting but not clear what they do" are stealth startups ***Berkshire Grey,***[44] ***6 River Systems***,[45] both staffed by former Kiva alumni; and ***NextShift Robotics***[46] which uses technology bought a failed effort at Harvest Automation.

EXHIBIT 8: **Fetch, Freight, Fetch!**

Source: Photograph by the author

[30] http://fetchrobotics.com/
[31] http://www.magazino.eu/?lang=en
[32] http://www.symbotic.com/
[33] http://www.adept.com/
[34] http://www.swisslog.com/
[35] http://autostoresystem.com/
[36] http://www.grenzebach.com/
[37] http://www.cdrobot.com/
[38] http://www.greyorange.sg/
[39] http://www.hitechroboticsystemz.com/
[40] http://www.cimcorp.com/index.aspx
[41] https://www.vanderlande.com/
[42] http://www.bastiansolutions.com/
[43] https://www.dematic.com/
[44] http://berkshiregrey.com/
[45] http://www.6river.com/#about-us
[46] http://www.nextshiftrobotics.com/about.html

NOT UNEXPECTED: INCREASING M&A AND INVESTMENT ACTIVITY IN AUTOMATION

Of course, increased interest in a technology attracts the usual characters out of the woodwork. Given the fast pace of technological progress, the timing is right for M&A activity from the providers of legacy technology towards those with the next big thing.

A quick summary of the latest and most notable transactions in the warehouse and general automation sector in the last few months:

+ **Honeywell acquires Intelligrated.** In July 2016, Honeywell announced it would acquire Intelligrated for $1.5 billion. Intelligrated is an integrator of mobile and stationary robotic automation solutions for manufacturing, warehousing, and materials handling.[47] Intelligrated reported $900 million in revenues and has 3,100 employees in the Americas and China. Honeywell is interested in building capabilities in logistics and Intelligrated seems like a good fit.
+ **The KION Group acquired Dematic.** In June 2016, the KION Group announced it would acquire Dematic for $2.1 billion. KION itself is a rollup, starting as the 2006 spinoff and sale of Linde AG's materials handling division to KKR in Goldman Sachs. KION then acquired Baoli, a Chinese lift manufacturer, in 2009. In 2012, Weichai Power, a Chinese diesel engine manufacturer, bought a stake in KION which then increased through a series of additional bolt-on acquisitions, including Retrotech, a US integrator of logistics systems, and Egemin, a Belgian maker of warehouse AGVs. Currently, Weichai Power is KION's controlling shareholder with a 38% stake.
+ **KUKA acquires Swisslog and then Midea acquires KUKA.** In 2014, KUKA acquired Swisslog for $357 million, and earlier this year Midea made an offer to increase its stake in KUKA beyond 49%. The deal remains pending (as of this writing KUKA shareholders have tendered 90% of KUKA shares) but it is one of the more interesting Chinese outbound investments consistent with the search for new technologies.
+ **ChemChina acquires KraussMaffei.** In January 2016, KraussMaffei,[48] a German maker of injection molding machinery and industrial robots agreed to be acquired by ChemChina for EUR 925 million ($1 billion).
+ **Paslin is acquired by Wanfeng.** In April 2016, Paslin, a Michigan-based integrator of welding robots and automation systems, agreed to be acquired by Wanfeng, a Chinese auto parts maker, for a reported $302 million.
+ **Gimatic is acquired by AGIC.** In June 2016, Gimatic, an Italian supplier of end-of-arm tools for industrial automation and robotics, agreed to a majority investment by AGIC, a Chinese-controlled PE firm for over EUR 100 million.

[47] https://www.intelligrated.com/
[48] http://www.kraussmaffei.com/en/home.html

ARE WE THERE YET?

Again, the autonomous vehicle DARPA Grand Challenges (*Weekend Tech Byte: Talk to the Hand*) point the way to how the Amazon Picking Challenge could evolve.

The technology of self-driving cars went from being a far-fetched joke in 2004 to "relatively competent" in 2007, to the real (technical) deal by 2016. We are now arguing as to whether self-driving cars are more of a killing machine than your average driver (*Weekend Tech Byte: Killing Machines*) or if they will make children lazy.[49]

Similarly the series of Amazon Picking Challenges are leading to the acceleration of technological progress in solving the picking problem. Would that lead to other problems? Possibly – the increasing levels of automation in warehouses is likely to impact those humans that rely on warehouse work to survive.

But that's a topic for another (more introspective and gloomy) *Weekend Tech Byte*. For the time being, we think this picking problem will be solved in a few years, opening new vistas and applications for flexible, high wow-factor factory automation.

Have a great weekend.

-AM

[49] https://www.youtube.com/watch?v=q2MfCEDLevO. This video really captures the *zeitgeist* of self-driving technology, where it's a given that it works, and the discussion is whether we want it to work or not.

DISCLOSURE APPENDIX

TICKER TABLE

Ticker	Rating		11 Aug 2016 Closing Price	Target Price	TTM Rel. Perf.		EPS Reported 2015A	EPS Reported 2016E	EPS Reported 2017E	P/B 2015A	P/B 2016E	P/B 2017E
2353.TT (Acer)	U	TWD	15.15	10.50	20.0%	TWD	0.20	0.37	0.17	0.69	0.69	0.69
5201.JP (Asahi Glass)	M	JPY	629.00	640.00	(23.3)%	JPY	37.12	25.95	33.35	0.66	0.70	0.69
2357.TT (Asustek)	M	TWD	265.50	300.00	3.7%	TWD	23.02	23.79	25.86	11.53	11.16	10.27
2409.TT (AUO)	O	TWD	12.70	12.00	28.7%	TWD	0.51	0.75	0.60	0.67	0.66	0.65
AUO	O	USD	4.20	4.00	31.1%	USD	0.17	0.25	0.20	0.67	0.66	0.65
GLW	O	USD	22.83	24.00	23.2%	USD	1.40	1.23	1.25	9.21	8.76	7.84
2308.TT (Delta)	O	TWD	173.00	195.00	5.8%	TWD	7.67	6.45	7.89	22.56	26.82	21.93
6954.JP (Fanuc)	O	JPY	17,315	22,000	3.3%	JPY	816.78	574.44	920.48	21.20	30.14	18.81
3481.TT (Innolux)	O	TWD	11.55	13.00	10.9%	TWD	0.98	(1.56)	(0.60)	0.61	0.53	0.53
992.HK (Lenovo)	O	HKD	5.33	6.00	(40.6)%	USD	(0.01)	0.03	0.05	(68.72)	22.91	13.74
034220.KS (LGD)	O	KRW	30,950	28,000	34.0%	KRW	2,860.29	1,976.33	2,046.75	0.97	0.91	0.87
LPL	O	USD	13.80	13.18	38.5%	USD	1.35	0.93	0.96	0.92	0.86	0.83
5214.JP (NEG)	O	JPY	467.00	700.00	(27.2)%	JPY	19.38	25.20	29.87	0.45	0.45	0.45
MXAPJ			448.22				30.52	30.38	33.73	14.69	14.75	13.29
MXJP			794.42				51.51	57.00	62.33	15.42	13.94	12.75
SPX			2,175.49				116.21	116.79	132.28	18.72	18.63	16.45

O - Outperform, M - Market-Perform, U - Underperform, N – Not Rated

6954.JP,992.HK base year is 2016. GLW valuation type is EV/EBITDA; 2357.TT,2308.TT,6954.JP,992.HK valuation type is P/E Reported. 5201.JP,AUO,GLW,6954.JP,LPL,5214.JP close date is 08/10/2016.

VALUATION METHODOLOGY

We value our companies using a mix of relative P/BV, P/E and DCF methodologies.

For Display Glass and TFT-LCD companies, given the volatility in earnings, we value the display glass stocks using book value. The valuation multiple is advised by our DCF models, which references a 10-year period to smooth the YoY cash flow and margin volatility, but with a downward trend.

For TFT-LCD companies, given the volatile and cyclical nature of the financials and shareholder returns, and high incidence of low or negative net income periods (which makes P/E multiples bad proxies for valuation), we follow industry practice and value TFT-LCD display companies on a price-to-book value (P/BV) basis. To determine the relevant multiple to apply, we review P/BV multiples at the firm level against historical and forward consensus profitability, cash flow and balance sheet data to estimate fair value multiples.

Automation companies, as well as PC OEM companies have more stable cash flows and reliably positive earnings, hence we triangulate using historical P/E multiples and SOTP DCF and RI models which incorporate the market value of unconsolidated subsidiaries and shareholdings.

RISKS

For Asian IT Hardware we see segment-wide and firm-level for our companies. In the Display Glass sector, profitability is driven by ASP, utilization, and to a lesser extent cost fluctuations. Supply-demand balance, product differentiation and pricing negotiation outcomes drive ASP change on a quarterly basis. In the TFT-LCD sector, profitability is driven by capacity utilization, so there is upside risk to our target prices from tightness in supply-demand balance, which increases production and fab utilization without material ASP reduction (and vice versa). Tight supply-demand balance can be brought about by higher unexpected demand or reduced supply. Automation companies are able to adapt to changing conditions. However, they are still exposed to segment-wide and firm-level risks. PC OEM companies are closest to the customer, and hence can respond the quickest to changing market conditions. On the other hand, they are the most exposed to product obsolescence and changing consumer preferences, and can run into issues of product proliferation, channel inventory buildups, or reputational risks.

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  Not Rated: The stock Rating, Target Price and/or estimates (if any) have been suspended temporarily.
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12-Month Rating History as of 08/10/2016

Ticker	Rating Changes	
034220.KS	O (RC) 08/31/15	M (RC) 06/24/15
2308.TT	O (IC) 01/26/15	
2353.TT	U (RC) 04/22/14	
2357.TT	M (RC) 06/29/15	
2409.TT	O (RC) 08/31/15	U (RC) 07/18/14
3481.TT	O (RC) 08/31/15	U (RC) 07/18/14
5201.JP	M (RC) 03/04/14	
5214.JP	O (RC) 09/11/15	M (RC) 03/02/15
6954.JP	O (IC) 03/09/16	
992.HK	O (RC) 04/17/13	
AUO	O (RC) 08/31/15	U (RC) 07/18/14
GLW	O (IC) 12/04/12	
LPL	O (RC) 08/31/15	M (RC) 06/24/15

Rating Guide: O - Outperform, M - Market-Perform, U - Underperform, N - Not Rated
Rating Actions: IC - Initiated Coverage, DC - Dropped Coverage, RC - Rating Change

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