ROBOTICS IN LOGISTICS

A DPDHL perspective on implications and use cases for the logistics industry

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PREFACE

Primed by scenarios from science fiction, as well as by hype and wild speculation from the world's media, we have for many decades anticipated the era of robotics. We are concerned that robots may steal our jobs and spy on us. We imagine that they will arrive not in ones and twos but in vast armies ready to alter forever life as we know it.

The reality is, of course, quite different. Exciting as it is, robotics technology seems to be arriving slowly but surely in cautious and well-considered stages. Right now robots are already among us. Personal robots are busy cleaning inside our homes and helping to maintain our gardens. Commercial robots are busy on the manufacturing side of the supply chain, mostly in the automotive sector. But where are all the robots in the logistics environment? Why are there so few advanced robots working in our warehouses, helping us to meet modern distribution challenges?

This DHL trend report explores these questions in detail. You will find that designing an advanced robot is expensive and a significant technological challenge. You will see that the distribution environment is complicated and difficult to automate. But every day there are breakthroughs in robotics, helping us to overcome these challenges. Funding is pouring into robotics research in unprecedented amounts from unexceed sources. And there are both large enterprise players and innovative startup companies focusing for the first time on extending the role of robotics beyond manufacturing and into the logistics side of the supply chain.

In this report, we examine the current state of robotics and automation in the logistics industry and offer a visionary outlook of how our supply chains will be transformed and improved by this emerging technology trend. You will extend your understanding of collaborative robotics with particular insights in the following areas:

- **Understanding robotics in logistics – why is the time right to start investigating?**
- **Which leading technology trends are enabling robotics solutions in logistics?**
- **What are some of the potential use cases in the near future?**
- **How could robots change the world of logistics in the far future?**

This report will prepare you for a new era of advanced robots in logistics, and we hope it will ignite your interest in the future of robotics. Enjoy the read!

Yours sincerely,

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1 UNDERSTANDING ROBOTICS

1.1 Robotics in Logistics: An Emerging Technology Trend

As highlighted in the DHL Logistics Trend Radar, there are several significant technology trends that will greatly affect our future in a positive way. Examples include sustainable energy, medical informatics, 3D printing, gene sequencing, big data analytics, and self-driving cars. It is easy to picture how advances in these areas will improve our lives.

Another major technology trend that will have a profound and positive impact on society is the development of advanced robotics. Every day, innovative robots are supporting doctors with surgeries that are less invasive and safer to perform. In hospitals, robots work with nurses to bring meals and medicines to patients without delay. Robots are being designed to remove dangerous landmines and support recovery from natural disasters in ways that would be too risky for human beings.

Robots work together with factory employees to assemble goods around the world with higher quality and at lower cost. Personal robots are available to help us around our homes by mowing the lawn, watering the garden, and vacuuming the living room. Robotic prosthetics and "exoskeletons" help restore functions of amputees and the elderly, allowing them to remain active in society.

These robots already advance our lives by eliminating tasks that are dangerous, repetitive, tedious, or boring and give us improved skills of accuracy, precision, and strength. Robots enhance our productivity and allow us to accomplish more each day even in a world where the working population is getting older.

Up until now, robotics technology has not made a large impact in the world of logistics. This is about to change as advanced robots enter our warehouses, sorting centers, and even help with final-mile delivery. Logistics workers will benefit from collaborating with robots, while customers will see faster service and higher quality. Imagine a world where people can focus on work that is meaningful and more enjoyable. Picture a world where repetitive, tedious, or dangerous manual labor is uncommon. Dream of a logistics supply chain that is faster, safer, and more productive.

This DHL trend report gives an overview of the current state of robotics in logistics, and offers a vision of how our supply chains will be transformed and improved by this exciting technology trend.

Figure 1: Robots help people in dedicated areas of everyday life and work

1.2 Robotics in Logistics: Why Now?

One of the biggest challenges facing the logistics industry today is labor availability. It's not easy for companies around the world to find enough high-quality employees to move goods from suppliers to customers. Two competing factors are making this especially difficult: The first is an increasing need for more logistics workers and this is being driven by the e-commerce revolution and its need for more parcel shipments; the second is a decline in the size of the available workforce due to shrinking population levels in the Western world.

Forrester Research predicts a 10% year-on-year growth for online retail in Europe[1] and the US.[2] Online growth in Asia is even faster; for example by the year 2020 the online retail market in China is projected to be equal to that of France, Germany, Japan, the UK, and the US combined.[3]

This growth directly affects the requirement for logistics labor since online retail typically needs more labor per item sold than traditional brick-and-mortar retail. This is because, instead of moving merchandise to a retail store in bulk, the organization must pick and pack online purchases individually by hand. Freight and parcel handling labor goes up as well since these goods must be shipped as separate parcels to be delivered directly to consumers' homes. Added to this, the average weight of these shipments is increasing as consumers can now order large items such as white goods, building supplies, and even furniture online.

For the first time in history, future populations will be smaller than past generations in the mature markets. A recent study by BCG shows that over the next fifteen years Germany alone could see a labor deficit up to 10 million workers.[4]

Figure 2: Online retail keeps growing fast

Since 1948, the US economy has grown at an average pace of 3% per year. If this trend continues and with the current rate of productivity, over the next thirty years the US will need 35 million more workers than will be available. How will companies fill this labor gap?[5] Even today employees are being asked to work additional years and retire later due to staff shortages, but logistics is a difficult occupation for an already aging workforce.

To combat these challenges, the managers of tomorrow's supply chains will need to either continue to raise costs while reducing service or will need to compensate with automation that can support workers and increase productivity. Today's current material handling automation solutions have helped to ease and postpone this challenge but in many cases the solutions are just not flexible enough to cover all of the requirements of a dynamic supply chain.

Could collaboration with robots be a possible solution to this problem? Could a machine that works with its human colleagues help fill the future gap between the required workforce and the available labor pool? Could robots help make logistics jobs easier so that employees can happily work into their 60s and beyond?

Figure 3: Economies will face shortage of million workers across different industries

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[1] http://nrw.nl/wp-content/uploads/2015/07/European-b2c-e-commerce-report-2015.pdf
[2] https://www.forrester.com/Forrester+Research+Online+Retail+Forecast+2015+To+2020+US/fulltext/-/E-RES125161
[3] http://www.china-briefing.com/news/2014/06/04/trends-chinas-e-commerce-market.html
[4] https://www.bcgperspectives.com/content/articles/management_two_speed_economy_public_sector_global_workforce_crisis/?chapter=2
[5] https://gbr.pepperdine.edu/2010/08/preparing-for-a-future-labor-shortage/

The desire to have a machine replicate human actions has been around for a long time. Over 500 years ago, Leonardo da Vinci drew plans in his sketchbook for a robotic knight that scholars believed could sit, stand, raise its visor, and move its arms.[6] In concept the arms were operated by pulleys, cables, and gears not unlike many of the modern robots that work in factories around the world today.

These mechanical humans were called automata and were designed to entertain and delight audiences. It wasn't until 1961 that the first industrial robot was sold to perform useful work, transferring parts from one point to another in a General Motors car factory.[7] Like that first robot, the vast majority of industrial robotic arms installed between the 1960s and today were confined to the manufacturing side of the supply chain, mostly in the automotive sector. Only a limited few transitioned to support logistics and distribution.

The main reason for the lack of logistics robots is technological. Until recently, robots have been stationary, blind, and relatively unintelligent. They perform the same movements over and over again thousands of times a day with a high degree of accuracy and precision. For many simple manufacturing processes, such as welding or transferring parts, these skills are all that are needed. The world of logistics, however, is much more complex than manufacturing and requires a robot with more ability.

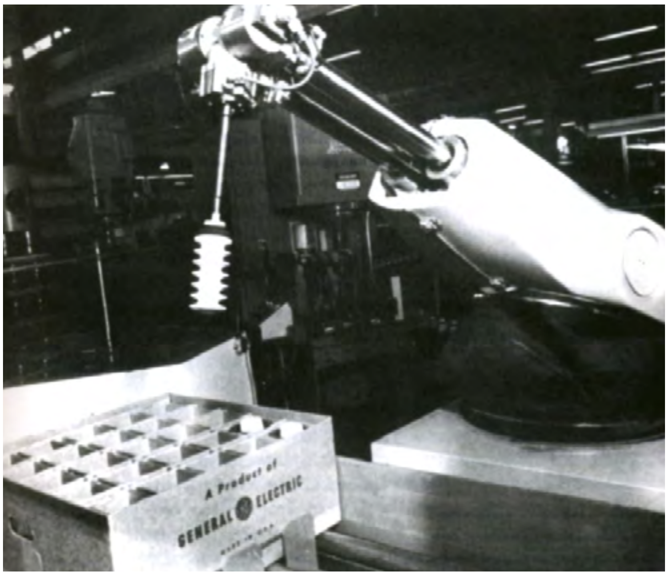

Figure 4: The Unimate on the General Motor´s assembly line in 1961; **Source:** Computer History Museum

A logistics robot would need to handle a wide array of different parts in an infinite number of combinations. It would help if the robot could see, move, and react to its environment.

Past attempts at putting more skilled robots into logistics applications have failed because the technology was just not ready. Until recently, robots were dangerous and had to be placed inside cages to protect passersby, making it very difficult to install them in the middle of a busy distribution center or have them collaborate with workers.

Figure 5: A logistics robot would need to handle a wide array of different shapes; **Source:** Deutsche Post DHL Group

Some robots were fitted with expensive cameras but they could only 'see' objects on a conveyor belt that matched a pre-programmed size and the exact shape that they were looking for. Any visitor walking through a sophisticated sorting center could quickly see that this approach would not work due to the infinitely variable stream of packages flowing by. Finally, industrial robots have been quite expensive, making them difficult to justify in businesses with low labor costs or that feature fewer than three operational shifts.

Robotics technology is finally beginning to catch up with our desire to have a robot that is flexible and low cost enough to work in the logistics and distribution environment. This trend report outlines the key changes that are happening today in the world of robotics; changes that should eventually lead to more effective robots across all areas of the supply chain.

6 "Leonardo da Vinci's Robots". Leonardo3.net. Retrieved 2008-09-25
7 http://www.robothalloffame.org/inductees/03inductees/unimate.html

1.3 History of Hype

Robotics is big news today. In the last twelve months there have been special sections about robotics in The Wall Street Journal, Time Magazine, The Economist, The Financial Times, Foreign Affairs Magazine, Geo, Wirtschaftswoche, and many others. Large consulting firms such as Deloitte and McKinsey published reports about advanced manufacturing and include robotics as a main driver for change. In fact, in 2015 over 80 research reports covering the topic of robotics were published.[8] Around the world several robot-focused business conferences have been held hosting large numbers of delegates.

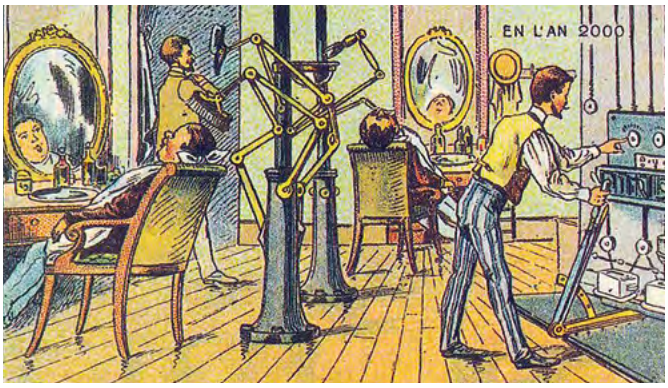

Figure 6: A 19th-century vision of the year 2000; **Source:** The public domain review

Many critical articles are being written about social acceptance of robotics and related ethical, legal, and societal (ELS) issues. Books such as "Rise of the Robots" and "Race Against the Machine" postulate that a robotics revolution is near and forecast that society will need to change to be ready for it.[9] Hollywood movies such as "I, Robot" and "Robot and Frank" show differing visions of the future with robots in our lives.

There is an ongoing public debate between those who believe that the number of jobs will decrease and those who believe that the number of jobs will go up as robots become more prevalent. A few well-known public figures such as physicist Stephen Hawking and Tesla CEO Elon Musk have warned that advanced artificial intelligence is "our biggest existential threat"[10] while Google CEO Larry Page believes that robots will improve lives, allowing people to spend more time with their family and friends while at the same time engaging in more rewarding work.[11]

The world has seen this type of excitement and hype before. In 1910, the French artist Villemard predicted robotic tailors and barbers taking over these professions by the year 2000.[12] In 1956, the Californian magazine Independent Press-Telegram dedicated its entire November issue to "You and the Year 2000". This article predicted that robotic farmers would take over by the millennium. On April 3, 1988, the Los Angeles Times Magazine produced a special issue predicting what life would be like for a family in the distant future of 2013 including "robot maids do all household chores".[13] Alas, if you have gotten a haircut recently or had to wash your own laundry you will know that the hype in the media regarding the future of robotics does not always come true.

These entertaining predictions were not fully wrong, however. In 2002 a company called iRobot introduced a robot vacuum cleaner for use in the home and since then the company has sold over 14 million home-cleaning robots worldwide.[14] This represents a small share of the total number of vacuum cleaners sold, but it is a start and several competitors have entered this market. While current news articles predict the coming of self-driving cars, the farm tractor manufacturer John Deere has already been selling self-driving tractors globally for several years.[15] In many cases media predictions for the future of robotics are not directionally wrong but their timelines are often too optimistic. Progress has taken much longer than many people would expect.

Why has progress taken longer?

The world of advanced robotics is very complicated and difficult. It is a multidisciplinary field that combines mechanical engineering, electrical engineering, and computer science but also draws on disciplines such as psychology, biology, neurology, sociology, and mathe-

8 http://www.therobotreport.com/news/is-the-robotics-industry-over-studied-or-does-it-indicate-a-trend
9 "Rise of the Robots: Technology and the Threat of a Jobless Future" and "Race Against the Machine: How the Digital Revolution is Accelerating Innovation, Driving Productivity, and Irreversibly Transforming Employment and the Economy"
10 http://www.bbc.com/news/technology-30290540
11 http://www.forbes.com/sites/ellenhuet/2014/07/07/larry-page-robot-jobs/
12 http://thesocietypages.org/socimages/2011/03/09/villemards-vision-of-the-future/
13 http://documents.latimes.com/la-2013/
14 http://www.irobot.com/About-iRobot/Company-Information/History.aspx
15 https://www.washingtonpost.com/news/the-switch/wp/2015/06/22/google-didnt-lead-the-self-driving-vehicle-revolution-john-deere-did/

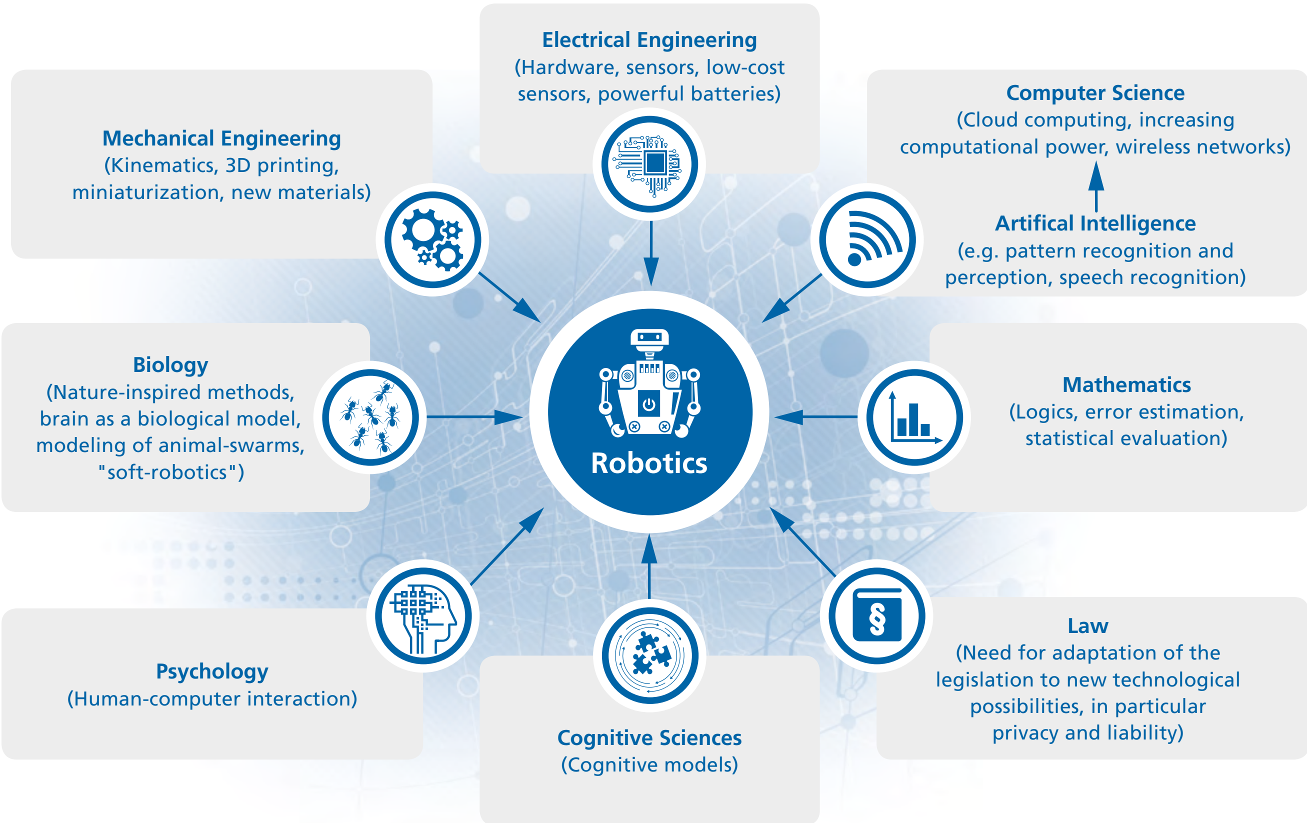

Figure 7: The world of advanced robotics; **Source:** Deutsche Post DHL Group

matics. To get a robot to do even simple actions often requires solving several challenging problems at once across multiple areas of study. For this reason, until recently, most robotics advancement and research was confined to the academic laboratory setting.

Besides the inherent technical challenges, several other obstacles have traditionally hindered advancement in the field of robotics: lack of research funding, expensive hardware and sensors, and limited computing power to run advanced algorithms in real time.

1.4 What is Different Today?

The past barriers to robots development are starting to come down. The first barrier involves funding. Developing the next generation of robotics will take a substantial investment to advance the technology significantly. In the past, research funding was typically limited to small university grants and the internal engineering budgets of industrial robot manufacturers – these are companies that tended to focus only on improving their existing applications within manufacturing. Today, a new wave of research and funding is flooding the market, and it is coming from three sources: government stimulus programs, venture capital investments, and large enterprise players such as Google and Amazon.

Due to the current excitement around robotics, several countries are providing significant grants in an attempt to foster the next robotics revolution within their own borders. In 2012 the US government gave a total of $50 million in university grants for robotics research to more than 30 groups.[16] These grants were the first step in the Obama administration's National Robotics Initiative (NRI) with the goal of creating the next generation of collaborative robots. In addition to this funding, the US Defense Advanced Research Projects Agency (DARPA) funds the DARPA Robotics Challenge, a contest to develop semi-autonomous robots capable of performing complex tasks at disaster sites.[17] So far, the US government has invested over $96 million including more than $3 million in prize money.

[16] http://www.nsf.gov/news/news_summ.jsp?cntn_id=125390
[17] http://www.theroboticschallenge.org/overview

China has become particularly interested in robotics and has overtaken Japan as the world's largest consumer market for industrial robots.[18] In April 2015 it was announced that China has teamed up with Russia to develop a $200 million robotics research center and startup incubator.[19] One month later, Japan's prime minister announced the creation of the Robot Revolution Initiative Council. Backed by 200 companies and universities, the council's five-year plan aims to deepen the use of intelligent machines in manufacturing, supply chains, construction, and healthcare, while quadrupling Japan's annual robotics sales from $5 to $20 billion by 2020.[20]

Governments are not the only organizations funding robotics research. Several startup companies backed by venture capital are using the research from university studies to develop the next generation of robots. One of the most talked-about robots in the media today is named Baxter and comes from a company called Rethink Robotics. Even though Baxter's sales have been limited, the market sees great potential and Rethink Robotics has raised $113 million in capital investment just to develop and advance its technology.[21]

A new startup company that is focusing on the distribution market is Fetch Robotics. Fetch has developed a robotic arm that drives around on a mobile base to pick items from a standard warehouse shelf and put them into an order tote. Fetch has received $23 million in venture capital, much of it from SoftBank, a Tokyo-based phone and Internet service provider that also recently invested $100 million in a robotics company called Aldebaran that has created the robot Pepper.[22]

Figure 9: Startup Fetch Robotics; **Source:** Fetch Robotics

Overall, venture capital invested in the robotics field for the first five months of 2015 exceeded all robot-related equity funding in 2014 combined.[23] Even the public is now investing in the potential of robotics. In November 2013,

Figure 8: Startup Rethink Robotics; **Source:** Rethink Robotics

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[18] http://www.forbes.com/sites/montymunford/2015/04/23/china-russia-team-up-on-200-Million-robotics-deal/
[19] http://www.prnewswire.com/news-releases/global-and-chinese-industrial-robot-report-2014-2017-300035358.html
[20] http://timesofindia.indiatimes.com/tech/tech-news/Japan-unleashes-a-robot-revolution/articleshow/47481845.cms
[21] http://www.bizjournals.com/boston/blog/startups/2015/04/rethink-robotics-closes-series-d-funding-with-40m.html
[22] http://spectrum.ieee.org/automaton/robotics/industrial-robots/fetch-robotics-secures-massive-20-Million-investment-from-softbank
[23] http://www.hizook.com/blog/2015/01/20/venture-capital-vc-funding-robotics-2014

a robot rang the closing bell at NASDAQ, highlighting the creation of the first robotics stock index. Robo-Stox attracted $54 million in just 2.5 months, which was invested in 77 stocks globally.[24]

Big players such as Amazon and Google represent today's third source of funding for the new world of robotics. Seeing the potential of robots, Amazon spent $775 million in 2013 to buy Kiva, another startup robotics company with a focus on warehouse logistics.[25] Amazon now claims to have 30,000 robots working in 13 fulfillment centers.[26]

In the span of twelve months, Google bought eight robotics startup companies including one that focuses on automatic trailer unloading using advanced perception and one that focuses on a branch of artificial intelligence called 'Deep Learning'.[27] Overall Google has spent a rumored $500+ million to get into the high-tech robotics game.[28]

Improved levels of investment funding, however, are not the only reason that the outlook for robotics today is much better than in the past. There have been some fundamental breakthroughs in enabling technologies that can be used to create the next generation of robots. These enabling technologies include low-cost sensors, faster computers, big data analytics, better batteries, cloud computing, and mobility. The effect of these important breakthroughs will be the focus of the next section of this trend report.

Figure 10: Google got into the high-tech robotics game;
Source: Popular Science

What is a Robot?

Figure 11: What is a robot?

Close your eyes and picture a robot in your mind. What do you see? If you are into movies, you might picture some sort of human-like machine as seen in a science fiction film. Your robot might walk and talk as it navigates the same environments as people do. If you work in a factory, you might picture one of the giant welding robots working 24 hours per day on a car assembly line. If you are into home gadgets, you might think of the Roomba robotic vacuum cleaner. These are, in fact, all robots but they are also very different from each other.

It is very difficult to create a definition of a robot that fits all possibilities. The Oxford English Dictionary defines a robot as "a machine capable of carrying out a complex series of actions automatically, especially one programmable by a computer".[29]

While this definition is true of a robot, it is so broad that it also captures self-driving cars, drones, conveyor systems, and even a soda vending machine. Self-driving cars and drones have been discussed in another DHL trend report so, for the purposes of this report, we will use the following definition for a logistics robot: "A robot with one or more grippers to pick up and move items within a logistics operation such as a warehouse, sorting center or last-mile".

[24] http://www.forbes.com/sites/jenniferhicks/2013/11/06/first-non-human-will-ring-closing-bell-on-nasdaq/
[25] http://money.cnn.com/2012/03/20/technology/amazon-kiva-robots/
[26] http://www.bizjournals.com/boston/blog/techflash/2015/10/amazon-now-has-30-000-mass-made-robots-at-its.html
[27] http://www.techrepublic.com/article/google-and-robots-the-real-reasons-behind-the-shopping-spree/
[28] http://techcrunch.com/2014/01/26/google-deepmind/
[29] http://www.oxforddictionaries.com/us/definition/american_english/robot

2 ENABLING TECHNOLOGY TRENDS

The majority of industrial robots working today perform the same movements over and over again all day long. These movements are repeated very precisely and accurately. For example, a robot that takes a part out of a die press places its gripper in the right spot with 0.1 mm accuracy. This exact positioning was most likely programmed by the engineer who set up the robot work cell. What happens if the part the robot is supposed to pick up is not there? Most of the robots in factories today have no feedback capability. If there is no part to pick up, most robots will still move to the programmed spot and continue to close the gripper onto thin air.

People have a major advantage over industrial robots – we are able to see an object, walk to it, coordinate our movements to grasp it, sense that we are holding it correctly, and make adjustments if anything goes wrong. We have the strength and ability to handle all sorts of objects and shapes with different sizes, surfaces, weights, and fragility. In the context of logistics, if we can see it on a shelf or in a box, we generally have the ability to 'pick it and pack it'.

Traditional manufacturing robots have no such ability – they are blind, dumb, and locked into place. The good news is that recent advances are just starting to change this. Universities and companies around the world are doing research in areas of computer science and hardware that advance the perceptive capability of robots to identify an object, locate its position, and plan a path of motion that will allow the item to be picked up. This is an extremely challenging technical problem to solve that even a few years ago was nearly impossible.

The ultimate robot to support logistics will need to have some form of "Eyes, Hands, Feet, and Brains". It will need eyes to see an object, hands to pick it up, feet so that it can move the object to another place, and brains capable of coordinating all these tasks. In this section we will discuss the technological advances that are currently underway that could eventually give our robots some form of "Eyes, Hands, Feet, and Brains".

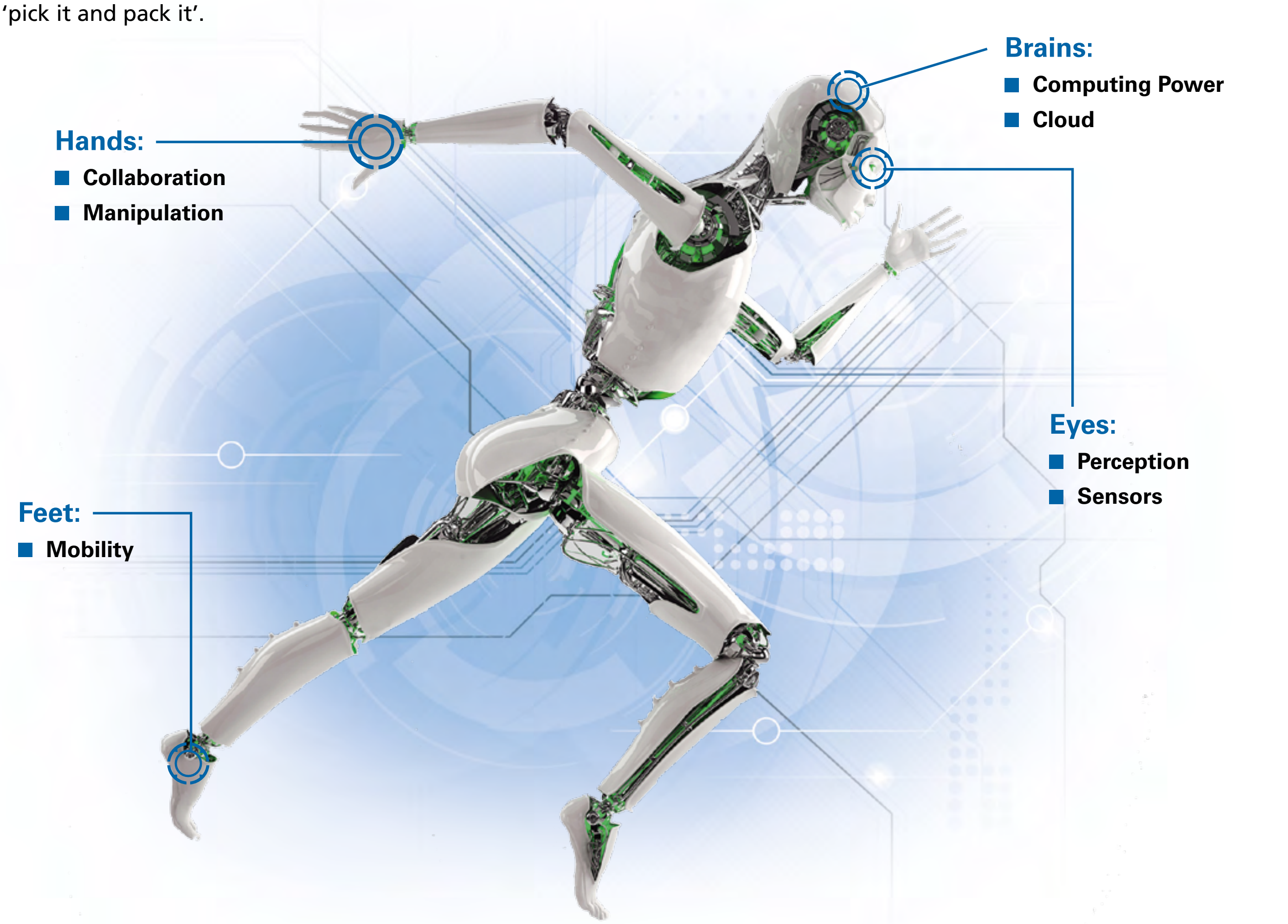

Figure 12: Technology trends enabling advanced robotics

2.1 Eyes: Accurate and Low-Cost Perception

Every day we use our five senses to navigate the world around us: sight, sound, smell, taste, and touch. If you were to buy a standard industrial robot from one of the big three robot manufacturers (ABB, Yaskawa, and Kuka), it would arrive with none of these senses. Typically what happens is that sensors, such as cameras and pressure switches, are added to each robot as needed by the team tasked with integrating the robot into the production process. These sensors are usually specialized, expensive, and often customized for each application.

Robotics engineers have been dreaming about lower cost and better sensors for years but there has always been a problem that stopped them. The industrial robot industry is not large enough to drive the economies of scale necessary to bring the costs of developing new sensors down to a reasonable level. There is one sector, however, that has been able to do this: consumer electronics. The next generation of robots will use advanced computer algorithms along with low-cost sensors developed for consumer electronics to greatly increase their ability to perceive the world around them. The *DHL Low-Cost Sensor Technology Trend Report* outlines further ways that low-cost sensors are impacting the logistics world.

Over the past two decades, digital cameras have benefited from a huge drop in the cost per megapixel. For example, back in 1992, Apple introduced one of the first home digital cameras called the QuickTake; its introductory price was $749 and it could store a grand total of eight photos in memory at a resolution of 0.3 megapixels.[30] Compare this to Apple's latest iPhones and you will find that after twenty-three years of progress these devices have two built-in cameras which cost the company less than $18 in parts and offer at least 25x the resolution of the QuickTake.[31] A key beneficiary of this low-cost, high-resolution camera technology is the robotics industry – now it is feasible to add 'Eyes' to the next generation of robots.

Mobile phone cameras are just one element that's being repurposed for the robotics world. Robotics startup company TakkTile has developed a low-cost touch sensor based on a mobile phone barometer. TakkTile's breakthrough technology can deliver 1 gram sensitivity for a fraction of the cost of existing systems, in a package durable enough to survive being crushed by a 25 lb weight.[32] Its sister startup company, Right Hand Robotics, has included this technology in a three-fingered robotic hand, enabling this hand to pick up a wide variety of items. Right Hand Robotics just raised $3.3 million in venture capital to continue its designs, and is currently working on developing an order picking system for use in distribution centers.[33]

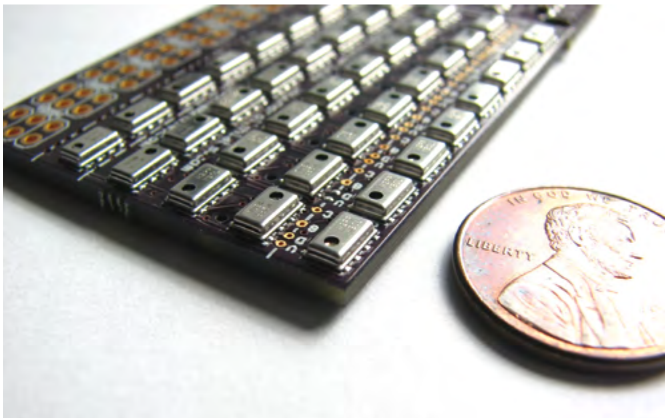

Figure 13: TakkTile´s touch sensor; **Source:** TakkTile

One specific consumer item has had a profound effect on robotics development, and it comes from the world of video gaming. For the 2011 Christmas season, Microsoft released its Kinect video game controller to the market. The Kinect is an inexpensive 3D camera system that can be attached to our home TVs. The camera can 'watch' a video game player and track their motion in real time. For example, if the person playing the video game swings their arm like they are using a tennis racket, the corresponding player in the video game would do the same thing. Players at home can jump, duck, punch, and in other ways move their onscreen characters, effectively becoming part of the game. While most of the world saw this as an advancement for home entertainment, robotics engineers saw this as an inexpensive sensor that could allow them to do things never before possible.

One reason that the Kinect has had such an impact is the quality of raw data that the low-cost sensor can provide in real time. The camera not only transmits color images of the items in its view but also provides the distance from the front of the camera to those objects.

[30] http://www.engadget.com/2009/07/29/retro-apple-the-quicktake-100-digital-camera/
[31] http://www.digitaltrends.com/mobile/iphone-cost-what-apple-is-paying/
[32] http://www.takktile.com/
[33] http://otd.harvard.edu/news-events/righthand-is-latest-robotics-startup-to-grab-venture-capital-xconomy

The Kinect can distinguish an object's depth within one centimeter of accuracy, and its width or height within three millimeters; and it is sensitive enough to see textures.[34] With advanced software, this information is good enough to allow a robot to 'see' its environment and locate objects that are in its view.

Due to the success of the Kinect, several companies are developing similar technology. One company, Leap Motion, has developed a comparable sensor for use with laptops that is 100x more accurate and retails for just $70.[35] Like all consumer electronics, this type of technology will clearly continue to increase in capability and decrease in cost over time. The robotics world is poised to benefit greatly from this trend.

Cameras alone are not enough to give 'Eyes' to a robot. Sophisticated software is also required to interpret the data from the cameras. The computer science discipline devoted to this research is called machine vision. One of the classic problems of machine vision that is of particular interest to the logistics field is the task called bin picking.

This requires the robot to use a camera to identify and pick up a single part out of pile of similar parts contained within a box. Once the image has been given to the computer by the camera, advanced programming is required to first identify a single part even if it is partially covered. After finding the part, the computer has to understand its orientation, ensure that it is a part that can be reached, and then plan a specific path for the arm to follow while

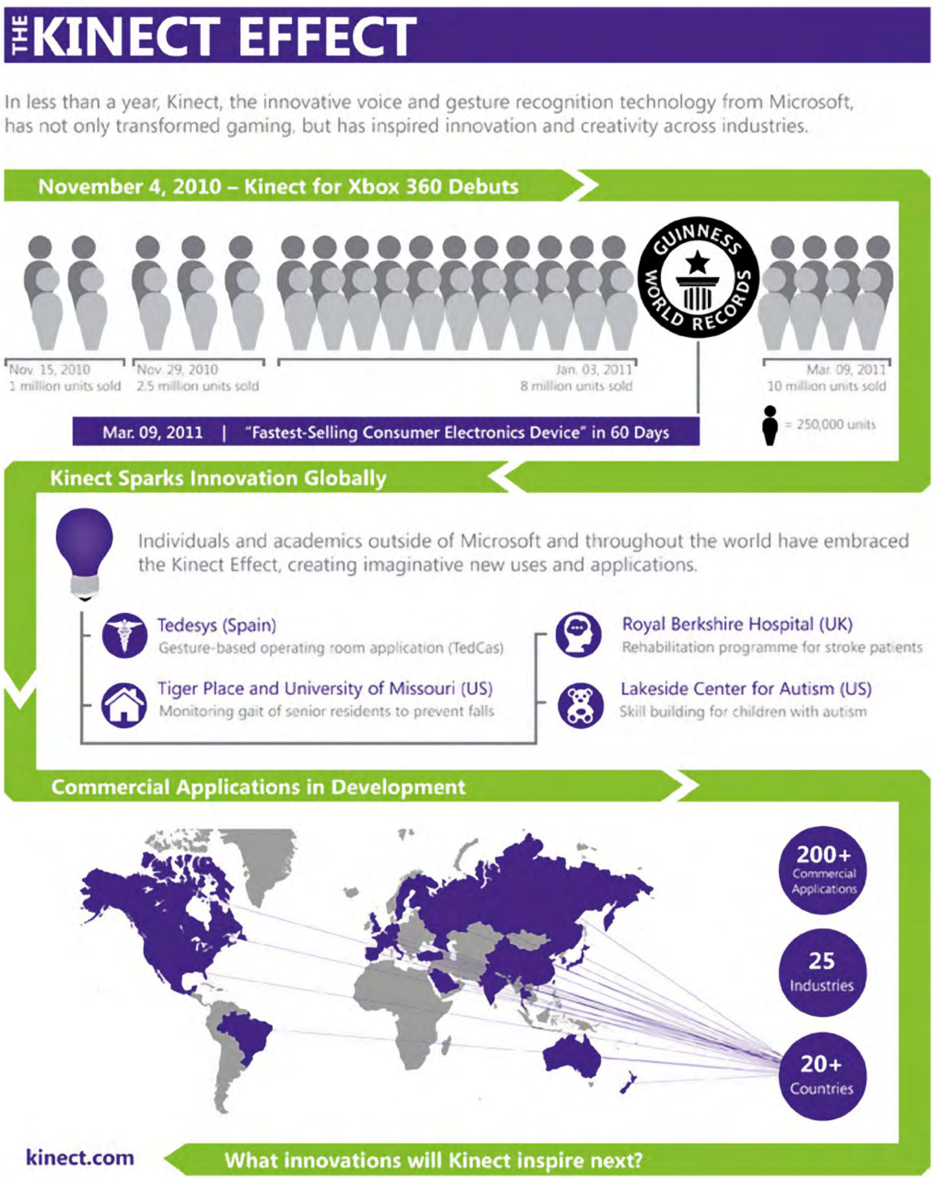

Figure 14: The Kinect Effect; **Source:** Microsoft

[34] http://www.wired.com/2010/11/tonights-release-xbox-kinect-how-does-it-work/
[35] http://www.theverge.com/2012/5/21/3033634/leap-3d-motion-control-system-video

calculating the proper orientation for the robotic hand to finally pick up the item. All of this has to be done at a speed that would make it interesting for industry. Several companies are working on this challenge and making significant progress. One example is Universal Robotics in the US.

This company has taken a unique approach, trying to make its software mimic the human brain. Using a Microsoft Kinect sensor and its own Neocortex advanced software, Universal Robotics has enabled a robot to 'learn' how to identify and pick up an item from a bin. Once one robot is trained to pick up a specific item, this knowledge can be transferred to other robots in the same warehouse or factory.

Pushing beyond the factory, several companies have used machine vision to build robots that work on farms and in orchards. The Spanish company Agrobot has developed a strawberry picking machine that uses several robotic arms with cameras to identify and pick ripe strawberries while leaving behind those that are not yet ready.[36] Other companies and research centers are developing robots to pick apples, oranges, and even cherries.[37] It is not difficult to see how advances in fruit picking robots could transfer into better logistics robots in the future.

Improving perception ability will allow robots to handle difficult tasks with a wider range of items in more complex environments. As perception gets better, we will first see more robots in our factories; we will then see robots in our distribution centers; and ultimately we may see robots as part of the final-mile solution, delivering packages directly to our homes.

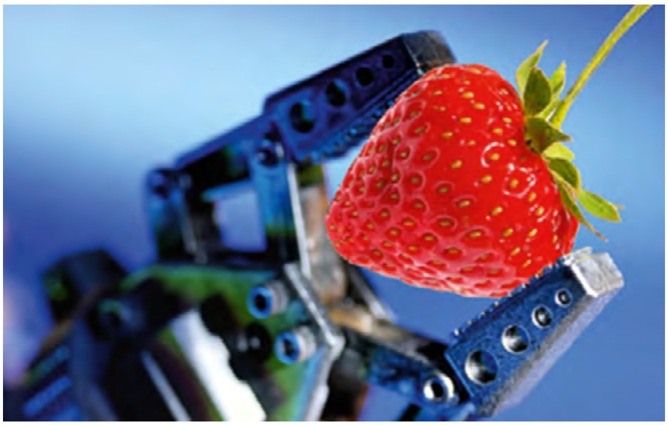

Figure 15: Strawberry picking machine; **Source:** Agrobot

Microsoft Kinect

Figure 16: Microsoft Kinect; **Source:** Microsoft

Within weeks of the Kinect's release, YouTube had dozens of home-made movies showing robots using the Kinect's 3D camera to navigate through rooms and obstacle courses.[38] Today several companies offer robotics solutions that have included the Kinect as their main sensor for finding objects in the environment. Why was the Kinect embraced so enthusiastically?

The first reason is the price. The Kinect retailed for $150 and combined an infrared depth camera, a color video camera, and a microphone array. To give perspective to this price breakthrough, just three years before the prototype for the Kinect cost $30,000 to build.[39] Microsoft spent more than $500 million dollars developing this technology with a team of over 1,000 people. Never before had the robotics world been able to access a sensor of this type at this cost.

The second reason for the Kinect's success is that Microsoft did not attempt to stop people from 'hacking' the system and repurposing it for other uses. In fact, after seeing the demand for the sensor, Microsoft released easy-to-use developer kits and professional versions of the sensor. Universities are now performing breakthrough research using the Kinect – technology that students could never have afforded to exploit in the past.

Microsoft's willingness to allow collaboration opened a large new market for Kinect beyond video gaming, and has inspired roboticists around the world.

36 http://www.pepperl-fuchs.com/global/en/27566.htm
37 http://www.wsj.com/articles/robots-step-into-new-planting-harvesting-roles-1429781404
38 http://www.wired.com/2011/06/mf_kinect/
39 http://www.nytimes.com/2010/10/24/business/24kinect.html?pagewanted=1&_r=2

2.2 Hands: Manipulation and Collaboration

No area of robotics has attracted more recent fanfare than collaborative robotics. A collaborative robot (also called a cobot) is designed to work with a human operator, positioned near them in a shared workspace. For example, the operator may perform the first part of a task while the cobot finishes the rest. In the world of logistics, this could include robots handling heavy parcels under human direction or taking on long travel moves to reduce human walking. According to a new study published by ABI Research, the collaborative robotics sector is expected to increase roughly tenfold between 2015 and 2020, reaching over $1 billion.[40]

One of the key aspects of the collaborative robotics concept is the idea of shared workspace. As already discussed, for safety reasons traditional industrial robots are normally locked inside large cages and are designed to shut down immediately if a person enters their workspace. Collaborative robots, on the other hand, are being designed as inherently safe to work around people. This involves new ideas for robotic arms including reducing their strength and speed, new types of joints, softer materials, and using advanced sensors to shut down the cobot safely if it accidentally collides with someone.

Figure 17: Artificial skin for robots; **Source:** TU Munich

A group at the Technical University of Munich, led by Prof. Dr. Gordon Cheng, has developed an artificial skin for robots that can sense touch, force, temperature, and vibrations.[41]

This skin even has the ability to sense 'pre-contact', meaning that the robot can sense when a person is within 10 cm of its arm. This feature to sense humans nearby has been successfully tested on industrial robots – these are capabilities beyond those that are currently available on the market. It is not difficult to imagine a future when all logistics robots will be covered with sensor skins allowing them to safely work alongside human workers.

> **"The ability of a robot to work around and among people will be critical when bringing robots into the logistics environment."**

Dr. Clemens Beckmann
Executive Vice President Innovation,
Post - eCommerce - Parcel (PeP), Deutsche Post DHL Group

Robots working in distributions centers will need to be deployed alongside traditional warehouse employees. In a parcel hub, sorting robots would have to work alongside truck drivers. If in the far future parcel delivery robots would become the norm, they would need to interact directly with human customers. In all scenarios it is apparent that collaborative robots within logistics would be more effective than non-collobarative robots.

For workers to accept robots as colleagues, designs must ensure smooth human-machine interaction as well as easy ways to reprogram robots and prepare them for new tasks. Many companies are working on robots that can be trained through touch screens and equipped with simple user interfaces. In several new designs, operators can actually touch and physically move the robotic arm, effectively 'teaching' the robot what to do by showing it. Non-technicians can now adjust, teach, move, and even install these robots, simplifying usage and reducing costs.

Robotic arms themselves have been getting less expensive. For example, between 1990 and 2005, the price of robotic arms dropped by 80%.[42] Since then, prices have continued to shrink and in the last few years a new low-cost category of collaborative robotic arm has entered the market.

[40] https://www.abiresearch.com/press/collaborative-robotics-market-exceeds-us1-billion-/
[41] http://www.cellularskin.eu/
[42] http://newsroom.iza.org/en/2015/03/31/robots-at-work-boosting-productivity-without-killing-jobs/

One company, Universal Robotics based in Odense, Denmark, manufactures small size collaborative industrial robotic arms. It sells a basic robotic arm with a controller for $34,000.[43] The robotic arm monitors the electrical current used by its motors and will shut down if it bumps into a person. At only 18 kg, the arm is made of lightweight materials further reducing its ability to harm anyone. Currently BMW is using various robot models from Universal Robotics alongside its workers in its South Carolina plant in the United States. The robots are performing assembly operations and BMW sees them as complementing, rather than replacing, its human work-force.[44] The market is certainly interested in low-cost robots that can work safely next to people as evidenced by Universal Robotics' annual growth rate of 70%+ and its recent sale to the company Teradyne for $350 million.

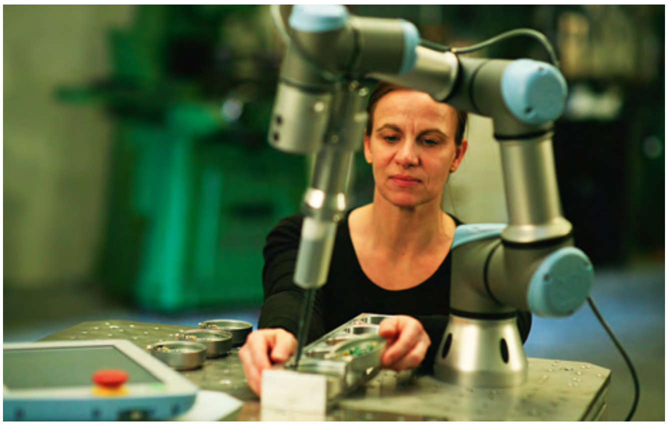

Figure 18: Robots working alongside workers; **Source:** Universal Robots

Larger robot manufacturers are taking notice of Universal Robotics' success. ABB Robotics has the second largest installation base of industrial robots in the world.[45] In 2015, the company introduced a new collaborative robot called YuMi, which stands for 'You and Me' working together. It is a two-armed robot that is priced at $40,000 and is aimed at the electronics and small parts assembly market. The YuMi's arms and torso are approximately

Figure 19: Collaborative robot YuMi; **Source:** ABB

the size of a small person and have a lightweight yet rigid magnesium skeleton covered with a floating plastic casing that is wrapped in soft padding to absorb impacts.

Due to YuMi's size and human-like configuration, ABB hopes that it can more easily be used on existing manual assembly lines alongside human workers. This idea of designing a robot that will fit well with existing manual operations and workstations will be another key element to help bring robots into the world of logistics.

Even with lightweight materials, sensors, and padding, many companies will not be comfortable implementing collaborative robotics until laws and regulations catch up with this new technology. Robot designers and regulators are working together to find solutions to ensure the safety of workers. The engineering and electronics company Bosch has recently released a robot that was the first in Europe to be certified for collaborative operations by the German Social Accident Insurance (DGUV) association.[46]

The Bosch robot is wrapped with its own version of a padded fabric sensor skin that can detect when a person is near. The robot will stop its movements when someone gets within a few centimeters and will resume its work when this person moves away. Innovations such as this will continue to make robots safer for use in our work-places and homes.

[43] http://www.roboticsbusinessreview.com/article/universal_robots_strikes_again_sells_to_bmw/RB13
[44] http://www.technologyreview.com/news/518661/smart-robots-can-now-work-right-next-to-auto-workers/
[45] http://roboticsandautomationnews.com/2015/07/21/top-8-industrial-robot-companies-and-how-many-robots-they-have-around-the-world/812/
[46] http://www.bosch-presse.de/presseforum/details.htm?txtID=6276&locale=en

Robotic Hand

Figure 20: Servo-electric 5-finger gripping hand; **Source:** Schunk

Most industrial robotic hands are either two-fingered 'pinch' grippers or rubber vacuum cups. The grippers are not flexible and are typically designed to match the specific items that they pick up. In many factory applications, the robot requires a change of grippers between tasks to ensure that it has the appropriate hand for the job. This approach is possible in a controlled manufacturing environment, but how would you handle picking up items in a truly unstructured environment, such as an ecommerce warehouse or sorting center?

The German company Schunk designs and sells robotic grippers around the world. It challenged its engineers to design a gripper that could handle a wide range of items. The answer was to follow nature and mimic the human hand with five fingers, twenty joints, and nine motors.[47] Available in both right- and left-hand models and weighing only 1.3 kg, this robotic hand is called the SHV. It can pick up heavy tools with a 'power grip' or delicate electronics with a 'precision grip' just like a human hand. DHL handles a broad range of differently shaped items and parcels each day requiring the ultimate material handling flexibility. Using a robotic hand that is modeled on the human equivalent may be the key to giving robots the flexibility needed to work in the logistics world.

2.3 Feet: Mobility with Intelligence

In factories, most industrial robots are bolted firmly to the floor. Since they blindly perform the same motions over and over again, they need to be precisely locked into position to ensure accuracy in their tasks. But these are robots designed around the Henry Ford assembly line concept, where workers stay in one place while cars flow in a controlled manner down the assembly line. If you've worked in the world of logistics, you will fully understand that a warehouse does not work like an assembly line. Allowing our future logistics robots to move around a warehouse, sorting center, or even our home towns requires some advancement in technology. Giving a robot 'Feet' takes more than just bolting on a set of wheels.

Already, there have been vast improvements in the field of mobile robotics including improved mapping of environments, better path planning, longer lasting batteries, efficient electric motors, high-speed wireless connections, and other innovations. Even the wheels themselves have undergone innovation with the development of omnidirectional wheels that can move a robot in any direction without turning. This section of the report showcases some example companies that are using these advancements to develop innovative mobility solutions that will give 'Feet' to our logistics robots of the future.

Knightscope is a startup company in Mountain View, California, US. It has developed a mobile security robot that will drive around a factory, warehouse, parking lot, or even a shopping mall. The robot is designed to detect anomalous behavior, such as someone unexpectedly walking through a building at night, and report back to a remote security center. Called the K5, the robot uses four high-definition cameras, two laser sensors, GPS, navigation equipment, microphones, a computer, and electric motors all packed into its dome-shaped body.[48] Its battery can last for 24 hours and the robot will automatically recharge itself as necessary. K5 patrols its environment avoiding objects and creating a map as it goes. It will stop abruptly if a person steps into its path and send warnings if someone tries to disable it. It can work inside or out, including on college campuses and at sporting events. It is not hard to see that this technology could be coupled with a robotic arm for warehouse picking or even eventually, with further development, repurposed as a package delivery robot.

[47] http://mobile.schunk-microsite.com/en/produkte/produkte/servo-electric-5-finger-gripping-hand-svh.html
[48] http://www.technologyreview.com/news/532431/rise-of-the-robot-security-guards/

Figure 21: Mobile security robot; **Source:** Slashgear

Delivery robots, in fact, are currently moving mail and supplies around offices, apartment complexes, and other large spaces. The company Savioke is selling a hotel robot called Relay that can travel from the front desk to any room to deliver snacks, towels, toiletries, and other requested items. When the robot arrives at your hotel room door, it politely calls you on your phone to let you know that it has arrived. After you enter a code into the robot, it will automatically open a compartment giving you access to your delivery. The robot whistles and chirps in a happy way to provide a positive customer experience. If there is an issue, you can contact the front desk directly through the robot and get immediate help. In 2015, Savioke's prototype fleet traveled the equivalent of 1,000 miles in five test hotels making over 5,000 deliveries.[49]

Besides working in hotels, delivery robots also transport medicines, meals, linen, documents, and supplies throughout hospitals. Aethon is a US-based company best known for mobile delivery robots that work in medical environments. Its flagship product, called TUG, is essentially a robotic cart mover that can pull carts from location to location as needed. The TUG can automatically traverse hallways, drive through doorways, travel up and down in elevators, and avoid pedestrians. A map of the hospital is created by Aethon's installation team and is then programmed with routes including use of elevators, automatic doors, delivery points, and charging stations. The TUG uses the on-board map for guidance and calculates its location in real time while it uses on-board sensors to adjust to the dynamic and changing hallways. The Aethon and Savioke robots are essentially automatic logistics delivery systems and show a glimpse of coming possibilities. Mobile robot technology will not only allow engineers to design robots that work within a warehouse but will eventually open up the possibility of allowing robots to drive on our sidewalks and streets delivering parcels directly to our homes and offices.

Swarm of Robots?

Figure 22: Swarm of robots; **Source:** Word Press

Leafcutter ants are known to group together to pick up and transport objects that are larger than themselves. Members of an ant colony 'talk' with one another to coordinate their activities by using chemicals which they smell with their antennae. Workers release pheromones with specific messages, such as "Follow me to food!" or "Attack the intruder!". This communication allows the ants to work together and creates an unplanned group behavior that is greater than any one individual. Scientists have called these coordinated actions 'emergent behaviors'. Roboticists often look to nature for inspiration. Swarm robotics is a new approach to the coordination of multirobot systems which consist of large numbers of mostly simple mobile robots. The robots are given simple rules to follow and, like the ants, can show emergent behaviors that are caused by interactions between the robots and their environment.

Kobi Shikar is a young student interested in robotics.[50] For a college design project in his native country of Israel, he envisaged a swarm robot concept he called TransWheel in which many small one-wheeled unicycle robots coordinate to perform logistics functions like delivering parcels. Kobi dreams of a future in which several of the robots group together to lift and transport a large box or even an entire shipping container. At this time there are several technological hurdles to overcome before this becomes reality. How many of these challenges do you think will be solved by the time Kobi graduates and can pursue his dream for real?

[49] http://www.savioke.com/blog/
[50] http://www.bbc.com/autos/story/20150824-meet-transwheel-the-self-balancing-autonmous-robotic-parcel-delivery-drone

2.4 Brains: Computational Power and Resource Sharing

When designing the next generation of logistics robots, there is one key element needed to tie together advanced perception, mobility, and collaboration: computational power, also known as 'Brains'. More than any one component, the rise of advanced robotics is clearly tied to improvements in computing speed and power. Advances in visual image processing, real-time obstacle avoidance, and other robotic functions all require access to cutting-edge mathematical algorithms and faster computers. Robots will continue to improve and take on more complex tasks as computational power increases.

Because computing speed is so essential, robot designers are pulling out every trick that they can think of to increase computational power. Once again the consumer electronics industry has led the way by developing speedy special-purpose computer chips called graphics processing units (GPUs) that are used inside computers and video game systems to very quickly calculate and draw the fast-moving game images that we see. Robot engineers have taken these GPUs out of the video game environment and started to use them to process visual images from cameras mounted on robotic arms. GPUs are often more than 10x faster at repetitive tasks than more general-purpose and well-known central processing units (CPUs). By using multiple GPUs in parallel, engineers can increase speeds yet again.

Increasing speed is not the only way to create better computer chips for robots. In August 2014, IBM introduced a new computer chip called SyNAPSE that works more like a human brain than a more traditional microprocessor. It is the largest chip that IBM has ever made and contains 5.4 billion transistors that emulate 256 million brain-like synapses.[51] The IBM development team feels that this chip will be better at processing visual signals than traditional computers while at the same time using significantly less power. IBM sees this chip as ideal for mobile robots including those in logistics applications.[52]

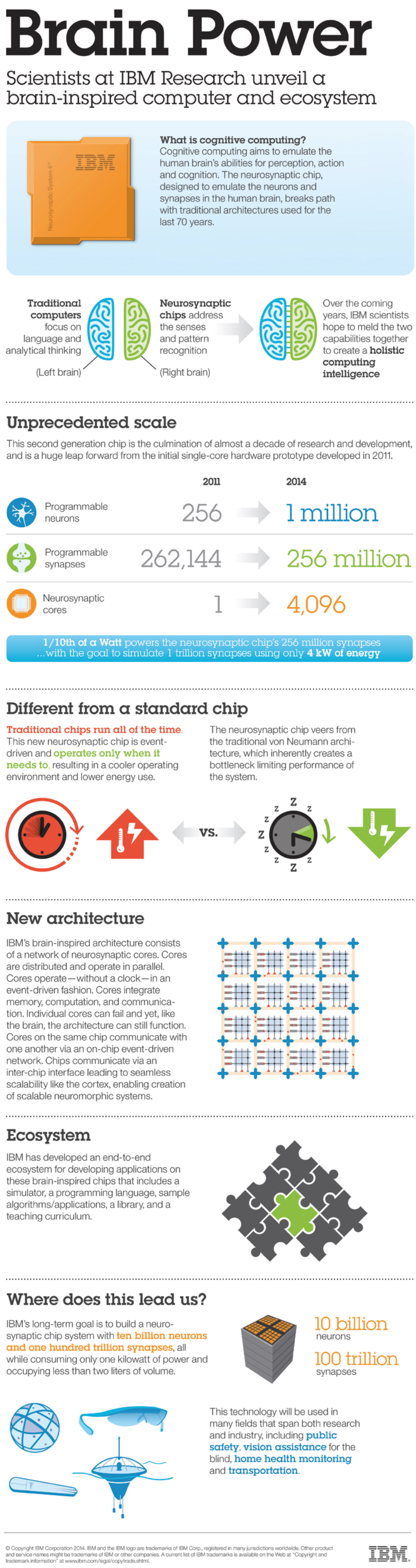

Figure 23: Brain power; **Source:** IBM

[51] http://research.ibm.com/cognitive-computing/neurosynaptic-chips.shtml#fbid=MzI_Ltl7_Hu
[52] http://www.cnet.com/news/ibms-truenorth-processor-mimics-the-human-brain/

While the IBM chip is very promising, we would need to put more than 500,000 of them into one robot to give it the equivalent capacity of the human brain. Of course a logistics robot would not need this level of computing power to be useful. It is likely that a logistics robot would only need narrow spikes of high processing power while the rest of the time it would need much less, for example when analyzing a camera image. This is the concept behind cloud robotics.

> **“If many ‘dumb’ robots could share one large ‘smart’ computer, each taking turns at thinking only when needed, we could lower the cost of each robot while greatly increasing its capability.”**

Matthias Heutger
Senior Vice President Strategy, Marketing & Innovation; Deutsche Post DHL Group

Cloud robotics emerged from the trend of cloud computing. Across the Internet, cloud computing allows multiple users to share common computer resources that may be located far away. For example, when you use your phone to search Google for an image, it is not your phone that is doing the work but rather a large array of fast computers at Google that very quickly search through billions of images in less than one second.[53] You are not the only person who is asking the Google computers to search for an image; in fact Google is asked to search for images over one billion times per day.[54] With its cloud computing approach, Google is able to service millions of unique users each day allowing everyone to benefit from their incredible IT infrastructure exactly when they need it.

In 2013 a team at the University of California, Berkeley, US, worked with Google to test a cloud robotics concept using Google Goggles image searches. Several objects were placed in front of a robot.

Using a camera, the robot would take a picture of an item and send it to Google’s computers. Using big data analysis (exploiting the volume, velocity and complexity of available information), the Google computers identified the item and sent back information to the robot on how to best move its hand to reach and pick up the object.[55] These preliminary tests proved that a cloud robotics approach could work in a real world environment.

The best example of cloud robotics currently available to the public is a humanoid robot called Pepper, a social robot that appears engaging, friendly, happy, and communicates with voice, touch, and simulated emotions. On sale since early 2015, the first 1,000 units sold out in less than one minute and 6,000 have been sold worldwide.[56]

Figure 24: Cloud robot Pepper; **Source:** Aldebaran

[53] https://googleblog.blogspot.nl/2010/07/ooh-ahh-google-images-presents-nicer.html
[54] http://www.bbc.com/news/technology-10693439
[55] http://queue.ieor.berkeley.edu/~goldberg/pubs/Grasping-with-Google-Goggles-icra-2013.pdf
[56] http://edition.cnn.com/2015/06/22/tech/pepper-robot-sold-out/

For a price of $1,600 you can buy a Pepper for your home to play with your children, act as a personal assistant, or even entertain your guests. Using an array of sensors, including two cameras and a microphone, Pepper can follow you around a room telling jokes, offering advice, and otherwise engaging with the people around it. Pepper speaks multiple languages and will attempt to understand your emotion state and react accordingly.[57]

How can such an inexpensive robot have these skills?

The robot is connected via WiFi and the Internet to a cloud computer in Japan where all of the difficult language and emotional processing happens while the individual robot only has enough computational power to do simple tasks.

Using the cloud approach gives Pepper some unique features. Its manufacturer, the French company Aldebaran Robotics, can add new languages to all Pepper robots at the same time just by upgrading its cloud computer. Much as with a cellphone, software upgrades can be automatically downloaded to the robot to improve various features and fix bugs as needed.

The robots will collectively record data from all of their interactions and use this to improve their performance over time. In one example presented by Aldebaran, if the robot reads a book that many children like, it may suggest that same book to more kids in the future.[58]

Cloud Robotics and Data Security

Figure 25: Designed to live with human; **Source:** Aldebaran

Social robots such as Pepper are designed to live with us in our homes. They have cameras and microphones that monitor what we do all day long so that they can properly interact with us when needed.

To keep hardware costs low, much of the data collected by these robots is sent via the Internet to a central computer for processing before instructions are sent back to the robot. How secure is this data stream? Could a hacker crack into the system and watch you through the robot's eyes? Or possibly worse, could the hacker take control of the robot and threaten to damage your house while you are gone?

New technologies always come with new challenges, and data security is one of the latest problems to affect our lives. The good news for robotics is that most of the security concerns related to cloud computing are well known and many companies are working hard to keep cloud computing safe. It is clear, however, that cloud robotics will give rise to new regulatory, accountability, ethical, and legal issues that society will need to resolve as fast as we knock down the technological barriers.

[57] http://www.dailymail.co.uk/sciencetech/article-3159392/What-s-like-live-Pepper-emotional-robot-Humanoid-gives-compliments-offers-advice-prattles-on.html
[58] http://spectrum.ieee.org/automaton/robotics/home-robots/pepper-aldebaran-softbank-personal-robot

2.5 Exoskeletons: The Ultimate in Human Robotics Collaboration

This report has already discussed how robots and people can work together side by side. Some engineers have asked: Is there a way to go even further and use robotics technology to not merely enhance but actually supplement human performance?

The term exoskeleton comes from nature and means outer skeleton. For example, many insects, crabs and lobsters have exoskeletons to provide support rather than an inner skeleton like humans do. Roboticists have morphed this concept into the dream of a 'robot suit' that a person can wear to give them the power, strength, and endurance that they would not normally have. The suit would strap onto the body using a harness attached to a robot frame, sensors, and motors that follow and support a person's movements as they lift and carry heavy objects.

In July 2015, the Japanese company Panasonic announced it will begin selling a robotic exoskeleton called the Assist Suit AWN-03.[59] Weighing less than 6 kg, this suit will retail for less than $9,000 and allow a person to carry 15 kg for up to eight hours on a single battery charge. Panasonic hopes to sell as many as 1,000 suits a year and plans to launch an improved version that will enable workers to carry up to 80 kg in the future. The company sees the logistics arena as a key market for this product line and plans to offer leasing options to help promote widespread adoption of this technology.

Harvard University in the US is working on developing a 'soft exosuit' that does not use rigid metal bars and jointed links.[60] The prototype suit is designed to mimic and enhance human muscles through the use of motors and cables. These soft systems have several advantages over a traditional exoskeleton. The suit is extremely light and the wearer's arms and legs are unconstrained by external rigid structures. These properties minimize the suit's unintentional interference with the body's natural movement making them more likely to be accepted by the wearer.

Other universities and private companies are starting to develop exoskeletons as well. They see the opportunity to improve working conditions for anyone who does repetitive or heavy manual labor in industries such as logistics, manufacturing, forestry, and construction. Exoskeletons promise people the opportunity to work more productively with less stress, fatigue, injury, and ergonomic problems. As people get older, exoskeletons will allow people to continue to be physically productive later in life, both at work and in our homes. Developments in robotics and exoskeleton technology will go hand in hand; improvements in one will benefit the other.

Figure 26: Soft exosuit developed by Harvard University; **Source**: phys.org

[59] http://www.ibtimes.co.uk/panasonic-mass-produce-alien-style-robot-exoskeleton-suit-help-workers-heavy-lifting-1509593
[60] http://biodesign.seas.harvard.edu/soft-exosuits

3 NEAR FUTURE – EXAMPLES IN LOGISTICS

The recent advancements discussed in this report have opened up new possibilities and now some designers have turned their attention towards logistics applications that were not previously possible. The goal of this section of the trend report is to highlight some examples of robotic systems for the world of logistics that are currently under development or even available today.

3.1 Current State of Robotics in Logistics

Research shows that 80% of current warehouses are manually operated with no supporting automation.[61] These warehouses have dealt with demands for increased productivity and throughput by supporting existing workers with good layout design, mobile material handling equipment, and constantly improving IT.

Some 15% of our current warehouses are mechanized. In addition to the technology used in manual warehouses, these distribution centers also use some type of material handling automation such as conveyors, sorters, goods-to-picker solutions, and other mechanized equipment to further improve the productivity of the existing workforce. While some of the components of these systems (ASRS / AGVs / shuttles) could be accurately considered as a type of robot, they are generally not in the same category as the robotic systems discussed so far in this trend report.

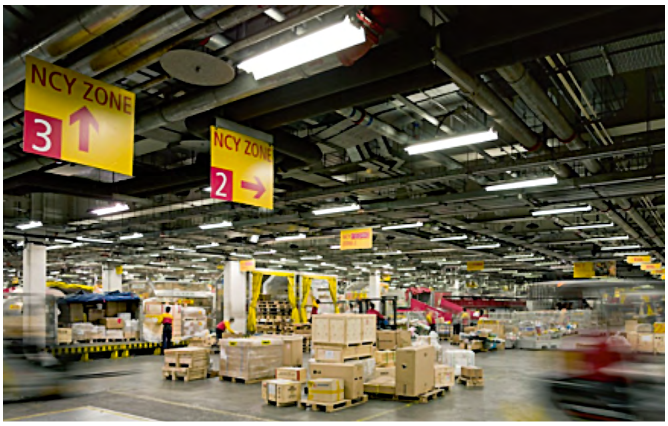

Figure 27: DHL warehouse; **Source:** Deutsche Post DHL Group

The research finds that just 5% of current warehouses are automated. The reality today is that these automated warehouses are typically highly mechanized environments that still employ people in key functions. An example would be a modern sorting center which has much higher productivity and accuracy than in previous generations. Even with all of this advanced technology, in large sorting hubs there may still be more than 1,000 employees who spend their time loading and unloading trucks, handling parcel ULD containers, and manually sorting odd-sized items.

3.2 Trailer and Container Unloading Robots

Many of the goods for sale in Europe and the US are made in Asia and most of these items cross the ocean in standardized shipping containers. To save on transport costs, the majority of these goods are loaded on the floor of the container and stacked to the ceiling without pallets. When the container arrives at a port, it is loaded onto a truck and sent to a distribution center. On arrival, the contents of the container are typically unloaded by hand, sorted, and stacked onto pallets so that they can be stored in the warehouse. This very manual and labor-intensive process can take several hours. Similarly, many long-haul parcel trucks are loaded floor to ceiling without pallets and require significant labor to unload.

In an attempt to deal with this problem, in 2003 DHL and its business and research partners worked to develop a new prototype – the Parcel Robot which consists essentially of the following components: a chassis, a telescopic conveyor belt, a 3D laser scanner, and a gripping system made up of an articulated robotic arm and a grabber. The robot is positioned in front of a container to unload and uses its laser to scan all of the boxes. An integrated computer then analyzes the various sizes of parcel and determines the optimal unloading sequence. The robot picks up a box and places it onto a conveyor that transports the item out of the container and into the sorting center.

[61] St. Onge Company internal survey of customers

Figure 28: DHL Parcel Robot; **Source:** Deutsche Post DHL Group

The robot moves forward as it works until the entire truck is unloaded. DHL never rolled out this concept across its network as in 2003 the technology was insufficiently mature to implement.

Nevertheless, DHL's innovative Parcel Robot proved to the world that robotic unloading was possible and several companies have since developed the concept further. A US company called Wynright currently offers a truck unloading robot for sale[62] Like the DHL Parcel Robot, it unloads boxes onto an extendable conveyor belt at a rate of over 500 parcels per hour.[63] Unlike the DHL robot, it uses low-cost cameras to locate the boxes rather than more expensive laser scanners. Over time this technology should become more cost effective, faster, and more reliable as cameras, computers, and robotic arms continue to improve.

Companies like Wynright are also developing trailer loading robots. This application adds further complexity to the software because the system now has to determine the best way to stack boxes of different shapes and weights to optimally fill the trailer without damaging any of the items.

3.3 Stationary Piece Picking Robots

A traditional warehouse employee typically spends most of his or her time walking around the warehouse to gather all of the items for an order. In a manual Amazon warehouse, a picker might walk between seven and fifteen miles per shift.[64] As previously mentioned, to save labor by reducing the time spent walking, Amazon bought the company Kiva that builds mobile robots. These robots can pick up a shelf of goods and bring the entire shelf to the picker who stays in one spot, effectively turning these humans into stationary assembly line workers. After the picker selects the needed items, the shelf moves away and a different shelf arrives to take its place. This so-called goods-to-picker concept can be found in several technologies on the market today such as Swisslog´s CarryPick mobile system. It is possible in some cases to save 50% of warehouse picking labor with these systems through the elimination of walking. Currently, most of these systems are very capital intensive, requiring a network of connected shelves, tracks, robotic shuttles, elevators, and conveyors. Even after this investment, they still require a significant number of people to pick items from an automatically presented plastic tote or mobile shelf.

[62] http://www.wynright.com/products/by-product-family/robotic-solutions/truck-and-container-loading-and-unloading/
[63] http://dhbusinessledger.com/Content/Richard-R--Klicki-s-Business-Tech/Richard-R--Klicki-s-Business-Tech/Article/Wynright-s-robot-brings-tech-to-the-loading-dock/107/197/9458
[64] http://www.businessinsider.com/working-conditions-at-an-amazon-warehouse-2013-2?IR=T

Figure 29: Goods-to-picker concept; **Source:** Swisslog

While these systems save walking, a relatively large labor force remains doing the very repetitive task of picking objects from one container and placing them into another. Besides being extremely boring, this is not ergonomically optimal for the operator; this person must perform the same set of movements over and over again with limited variation in the task.

The companies that make the large goods-to-picker material handling systems have seen this problem as an opportunity to introduce robotic arms into their systems. An example is the German company SSI Schaefer that offers a product called Robo-Pick.[65] This is a typical stationary industrial robot that is bolted inside a traditional robot work cell. The robot uses a camera to identify items in a plastic tote which has been delivered to the work cell by one of SSI Schaefer's large automated tote storage and retrieval systems. Once the robot has located an item, it picks the product up and places it on a small buffer conveyor that will ultimately deposit the item in a separate transport tote. SSI Schaefer claims that its robot can pick up to 2,400 items per hour depending on product characteristics and order profile. Currently the system seems to work best with small rectangular products such as DVDs and pharmaceutical boxes.

Similar systems have been developed by the companies Knapp and Viastore.[66] Knapp's system can automatically change its vacuum cup gripper to better match the product, while Viastore's system not only picks an item but can also place the item into a final shipping carton as well.[67]

In order to stimulate progress, Amazon took an innovative approach. In 2015, the company launched a robotic piece picking challenge to the world. Amazon offered a $20,000 prize to anyone who could build a robot capable of identifying and picking the most items from the shelves it uses in its Kiva system. Twenty-eight teams entered the contest and went head to head to compete for the prize. Two things were immediately apparent. First, there were as many different ways to tackle this problem as there were competitors. Second, it is still a very difficult problem to solve. The winning team was a group of researchers from the Technical University of Berlin, Germany; their robot successfully picked ten items while the rest of the contestants were far behind.[68]

Figure 30: Pick it easy; **Source:** Knapp

"Recent developments in robotics might turn out to be a game changer for the logistics industry. Robots now are able to perceive, pick, manipulate, and place a wide variety of objects in less and less structured environments. The technologies we developed proved to be crucial for winning the challenge, and we hope they will enable further advances in logistics and other industrial applications, boosting productivity, reliability, and profitability."

Prof. Dr. Oliver Brock
Robotics and Biology Laboratory,
Technical University of Berlin

[65] http://www.ssi-schaefer.us/automated-systems/systems-products/picking-systems/schaefer-robo-pick.html
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[67] http://us.viastore.com/order-picking-systems/viapick/
[68] http://www.engadget.com/2015/06/01/amazon-picking-challenge-winner/

One of the best things to come out of the Amazon challenge is that these new bright students are not afraid to tackle logistics problems and see that there is still great potential to impact the future.

These systems show a lot of promise and will improve over time as vision technology and grip planning algorithms are refined, allowing for a wider array of items to be handled beyond small rectangular boxes. There is one major downside to this approach, however. It is the need for a large and expensive goods-to-picker system to support the robots. Another issue is that these large systems are not easy to move from one building to another when a distribution network changes. In most cases the system would need to be scrapped instead of moved, due to its complexity and sheer size. These systems may be affordable for the largest warehouses but what about mid-size to small operations? Could robotic picking be developed to eliminate the need for a goods-to-picker solution?

The Amazon Picking Challenge Winners

Figure 31: Amazon Picking Challenge Winner; **Source:** TU Berlin

When Amazon issues a challenge, the world listens. The Amazon Picking Challenge was a contest held in 2015, designed to drive advancement in the area of automated piece picking with robots. The event attracted teams from around the world including Canada, China, Germany, Italy, Singapore, Spain, and the US.

At the end of the event there was no question about who was the winner. With a 60-point lead over their nearest competitor, the German team RBO from the Technical University of Berlin won the contest convincingly. In only a few short months, the team of German researchers had combined a robotic arm, an omnidirectional mobile robotic base, several sensors, and some advanced computer algorithms to create the winning system.

Based on the great outcomes of this event, Amazon has announced that the contest will be conducted again in 2016. This time it will be held in Leipzig, Germany.

3.4 Mobile Piece Picking Robots

The opposite of the goods-to-picker system would be a mobile robot that drives around traditional warehouse shelves and picks items just like a person would. Several startup companies are currently working on robots that can do just that.

IAM Robotics is a small company based in the United States. It is currently developing a mobile robot with an arm on top and a camera system that can navigate an existing warehouse and pick items from shelves and place them into an order tote. The system was first field tested in a pharmaceutical warehouse in New York where it was able to pick test orders from 40 items that it had never seen before.[69] The robot will be tested next in a more general goods warehouse where it will be integrated with a warehouse management system (WMS) for the first time and pick live orders. IAM Robotics hopes to have a commercial version of its system available sometime in 2016.

The company Fetch Robotics is a well-funded startup that is also developing a robot that will drive around a warehouse picking items from shelves. Its primary robot, called Fetch, can extend its torso to reach upper shelves while a small secondary robot, call Freight, helpfully holds the tote that Fetch will pick items into. Each Fetch robot can have several of these smaller Freight robots supporting the picking process. The agile Freight robots quickly move the totes around the warehouse from area to area while the slower Fetch robots can stay in one aisle and focus on picking items. This effectively creates a hybrid of the goods-to-picker approach and the traditional manual picking concept. Fetch Robotics intends to also sell the smaller Freight robots separately; these can be used to help human workers in warehouses containing items that are too complicated for the Fetch robot.

[69] http://www.logisticsmgmt.com/article/the_robots_are_coming_part_iii

Figure 32: Fetch and Freight; **Source:** Fetch Robotics

Magazino is a German startup company that develops and builds perception-driven mobile robots for intralogistics. Its latest development is the picking robot TORU. Using 2D and 3D cameras and Magazino's technology, this robot can identify individual objects on a shelf, grasp an item securely, and place it precisely at its destination. TORU works alongside humans, providing just-in-time object delivery to the workbench or shipping station. DPDHL plans to test TORU in a fulfillment center for 2016.

Figure 33: Mobile piece picking robot; **Source:** Magazino

There are still technical and cost challenges to overcome before these robots will be ready for widespread use but they have some key advantages over stationary goods-to-picker robots. First of all, the concept is much more scalable. If you have a small distribution center, you may only need one or two mobile robots and you could add robots one at a time as you grow. One can even envisage renting or leasing the robots; the warehouse could first test a few of them during low times and later rent more during busy periods when more help is needed. These robots could work alongside existing workers, picking easy items while the humans pick the more complicated products or focus on solving exceptions. Moving to a new warehouse would be easier since the robots are not bolted to the floor and a market for used robots would develop, reducing investment risk.

3.5 Co-Packing and Customization

The next time that you walk through a grocery store, take a look at all of the different ways that products are displayed. You will see items with special 'half off' price stickers or you might see two items bundled together so that you can 'buy one get one free'. Retailers have found that these modifications will catch our eye and cause us to buy more. This is a great sales device but it is expensive because adding all of these stickers, building the displays, and repackaging items takes a lot of labor and space. The retailers don't want to deal with this extra labor so they have decided to push this problem to their suppliers. Now every major producer of shampoo, batteries, soup, and other merchandise is at risk of receiving requests to modify their products specifically for key customers, often with very little advanced warning. These last-minute modifications are often referred to as co-packing or customization.

In many cases, the customization process involves opening a box of products, taking out the items, doing something simple to them like putting on a sticker, and then packing the items back into the box. The processes are not normally difficult; they just take up space and require a lot of labor. The key to being a good co-packer is flexibility since every day means working with different products and slightly different modifications. Traditional industrial robots do not have this kind of flexibility so most co-packing is done manually.

Earlier in this report we mentioned the robot Baxter from Rethink Robotics. Let's describe Baxter in a bit more detail to highlight some of the things that make this robot special. Baxter is a collaborative robot and is designed to work safely around people. Its two arms are plastic; it has springs in its joints and sensors to shut off the arms if they hit something. There is a sensor in Baxter's head that scans around the robot causing it to slow down if people come close, and Baxter has three built-in cameras that it uses to identify and pick up objects. Baxter plugs into a normal wall outlet and can be set up in minutes by someone with little or no training. Rethink Robotics can automatically download software updates to the robot as needed to improve its performance over time, and an update in June 2014 made the robot twice as fast and twice as precise.[70] One key goal for Baxter's design team was to create a robot that an average person could train just by grabbing one of the robot's arms and leading it through a simple task. This would allow Baxter to 'learn' the task and perform it over and over again. All of these capabilities are now available for the unheard-of low price of $30,000 per robot.

Figure 34: Baxter at the DHL Asia Pacific Innovation Center; **Source:** Deutsche Post DHL Group

In theory, Baxter should be perfect for co-packing since it was originally designed for end-of-production-line packing applications. DHL has purchased several Baxter robots and is currently evaluating the system in a laboratory setting. Baxter was a first-generation model for Rethink Robotics and, although it incorporated innovative ideas and new technology in ways never before seen, testing has shown that it cannot yet handle all common co-packing tasks. Recently the company has developed a second robot, called Sawyer, that is supposed to solve many of the issues found with Baxter while keeping the positive aspects. Time will tell if Sawyer or Baxter will be a success in the market. As with Baxter, DHL will soon be testing Sawyer to determine where it might fit into the world of logistics.

In many ways, Baxter exemplifies the story of the modern logistics robot. The technology is not quite ready but it is evolving fast and shows great promise. New ideas, low-cost sensors, faster computers, and innovative robotics are being combined in research laboratories around the world. Soon a few of these robots will live up to their hype and be ready for prime-time, causing a revolution in the way that we think about logistics.

3.6 Home Delivery Robots

In November 2015, a startup company in London, UK, called Starship Technologies announced that it will begin building and selling parcel delivery robots.[71] Started by two of Skype's original co-founders, the company already has strong funding and a team of engineers.

Although only at the prototype stage now, the Starship team is dreaming big. It is developing a small mobile robot that can drive on sidewalks at 6 km/h and deliver packages directly to consumer homes. Capable of carrying the equivalent of two grocery bags, the goal is for the robot to complete deliveries within 30 minutes from a local hub or retail outlet. Customers will be able to choose from a selection of short, precise delivery slots – meaning goods arrive at a time that suits them. During delivery, shoppers will track the robot's location in real time through a mobile app and, on arrival, only the customer can unlock the cargo with their phone. It is intended that the robot drives autonomously while, at the same time, it is overseen by human operators who can step in to ensure safety at all times.

Starship Technologies is currently testing and demonstrating prototypes and plans to launch the first pilot services in the UK, US, and other countries in 2016. Some competitors to Starship, such as the California-based Dispatch Robotics in the US, also plan to run real-world tests in 2016 while others, such as Ecotranzit[72] are still in the concept design phase.

The ground delivery robot concept is an interesting companion to the idea of using drones for delivery. You can learn more about drone delivery in the *DHL Unmanned Aerial Vehicles In Logistics Trend Report*.

Figure 35: Home delivery robot; **Source:** Starship Technologies

70 http://www.betaboston.com/news/2014/06/19/baxter-gets-faster-as-rethink-gives-its-worker-robot-an-upgrade/
71 https://www.starship.xyz/
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4 FUTURE VISION

Throughout this report, we have seen many important improvements in robotics technology, along with clear evidence that robots are now starting to enter the world of logistics. In the preceding chapter, we explored the innovative new technologies that, with further development, could soon be ready for full-scale testing. So looking ahead, in this chapter we consider what will happen when these latest technologies mature and become widely available. The following is one possible snapshot of our future.

4.1 Distribution Centers

Compared with the distribution centers of today, the robotic warehouses of our future are likely to improve in almost every metric. These highly scalable facilities will be more flexible and faster to relocate; they will achieve higher productivity with increased quality.

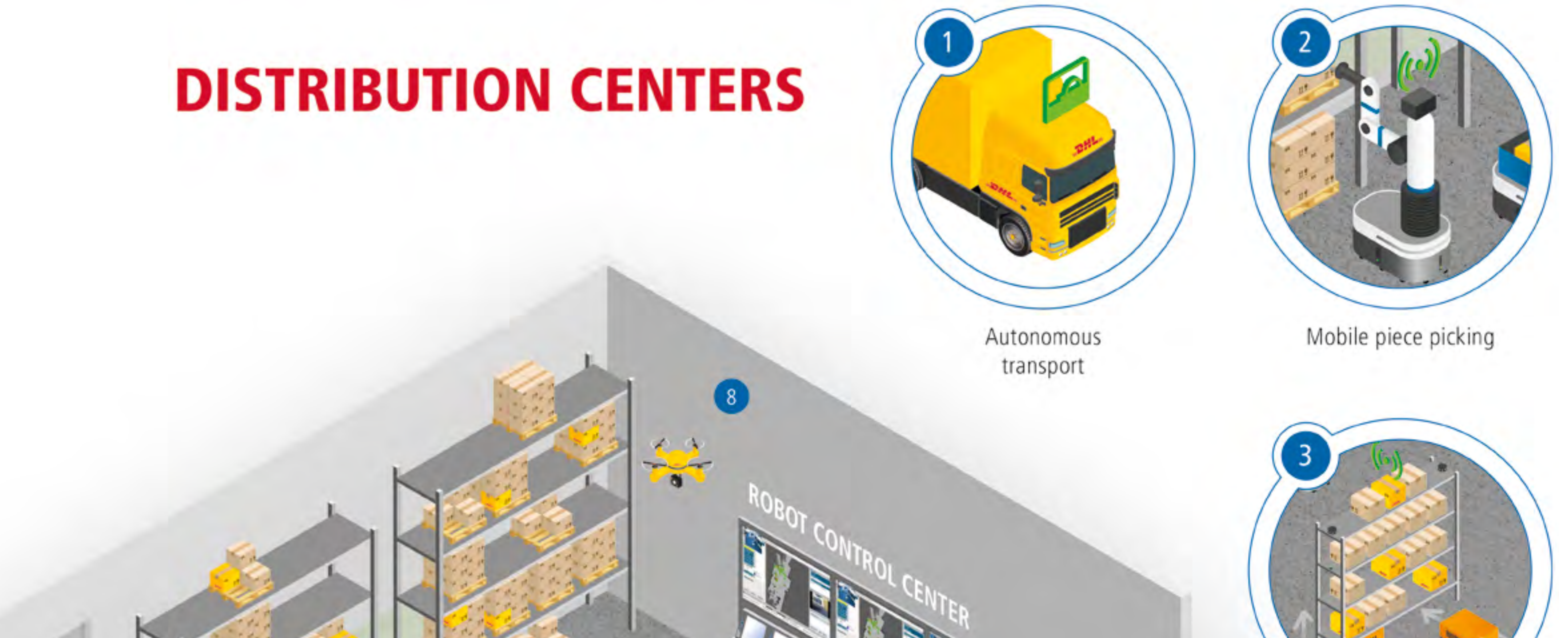
New operations will incorporate different types of robot each with a specific job to perform such as unloading trucks, co-packing, picking orders, checking inventory, or shipping goods. Most of these robots will be mobile and self-contained but they will be coordinated through advanced warehouse management systems and equipped with planning software to track inventory movements and progress orders with a high degree of accuracy.

Overall reliability will increase because there will be fewer 'single points of failure' in each distribution center. As each robot acts as an individual unit, we will be able to quickly push it to the side if it breaks down and replace it with another unit from the robot fleet. Depending on the problem, we will be able to fix the broken robot on site or send it to a central repair facility. The new robot will be connected to the cloud so it will automatically download the knowledge needed to take over from its decommissioned counterpart.

Warehouse workers will be given more responsibility and higher-level tasks such as managing operations, coordinating flows, fixing robots, and handling exceptions or difficult orders. They will wear exoskeletons to help them lift heavy goods with less strain, fatigue, and chance of injury. When necessary, we will bring goods into a co-packing area where collaborative robots will work safely alongside highly skilled warehouse employees to transform basic products into new items customized for individual orders.

Employees will train the robots through simple interfaces to do easy and repetitive tasks, and these humans will take on the more challenging work themselves. Both small and large warehouses will enjoy productivity gains as we add – on an as-needed basis – the robots that have proved to be successful in supporting the existing workforce.

Workers will be able to flex and scale operational capacity according to changing demand simply by adding more robots to cover peaks and automatically removing them from the building (relocating them to where they are next needed) to rebalance the distribution network.
And we will experience the emergence of a robot leasing, rental, and pre-owned market allowing companies to reduce capital investments while further increasing operational flexibility.



4.2 Sorting Centers

Unlike today, the sorting centers of the future will run continuously, 24 hours per day, to better align with the distribution centers that will also operate around the clock. Robotic warehouses and sorting centers will be just as effective on the last shift as they are on the first shift. Working in waves, the new supply chain will facilitate multiple shipments to end customers each day. By fully utilizing equipment across shifts, we will be able to lower logistics costs and, by processing multiple daily delivery waves, we will achieve faster service to end customers. Goods will be brought to the sorting center by self-driving trucks. These will arrive according to specific scheduled timeslots, and we will be able to efficiently control truck movements onto and around the yard using GPS and a yard management system.

When a truck arrives at the dock door, robots will unload it and sort the parcels according to final destinations. There are several possible approaches to accomplish this. For example, we could think of using a large number of mobile robots to transport the parcels from inbound dock doors to the appropriate loading areas. Each mobile robot would be loaded with parcels by a robotic arm; it would then group and sequence itself with other mobile robots to efficiently transport loads throughout the sorting center. When a truck arrives with dangerous goods, these will be automatically sorted, handled, and transported separately and securely. All of these tasks will be supervised by employees working in a robot-control center; these humans will address any issues, manage workflows, and make key operational decisions. Employees will also handle any exception parcels such as items that require repacking, relabeling, or a customs check.

When leaving the sorting center, most parcels will be loaded by robotic arms into line haul trucks which take them to the next sorting center in the network. Some items will be loaded into drones for airborne delivery to hard-to-reach addresses. Local delivery items will be loaded into mobile parcel robots which take them to individual homes in the surrounding area. And if the recipient is a high-priority customer, they will be able to send their personal self-driving vehicle to the sorting center; they can continue with their busy day elsewhere while their parcel is placed automatically into the trunk. It's clear to see that the advantages of these futuristic sorting centers – speed, flexibility, higher productivity, and more – will translate into better service for end customers, achieving faster delivery at a lower cost.

SORTING CENTERS

4.3 Last-Mile Delivery

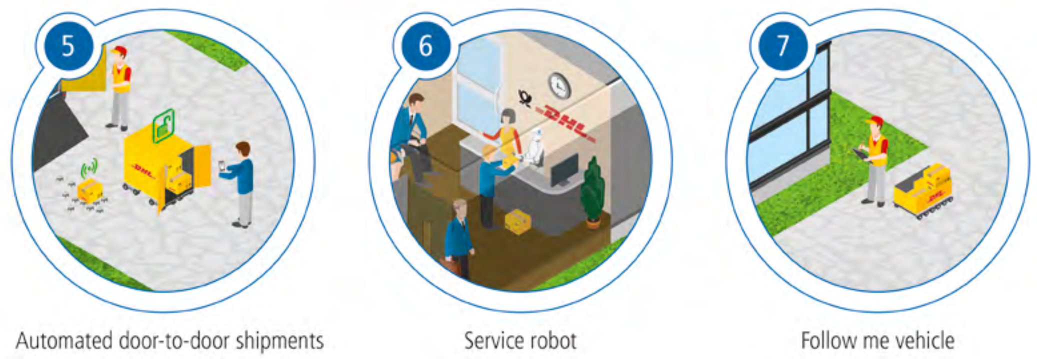
In future, the general public will interface with robots on a daily basis. We won't fear for our physical safety because these robots will avoid bumping into us using advanced sensors such as cameras, laser scanners, and proximity sensing skin. Using cloud computing techniques, these robots will provide high-quality customer service; they will be able to speak our language, react to our emotions, and access appropriate account information to ensure successful interaction. The first robots that we are likely to encounter are the ones at local parcel service centers. Here, a robot assistant may help us to ship a present to an old friend.

Another everyday occurrence could be the receipt of an email informing us that there's a small package for collection at a mobile parcel locker located outside a nearby store. How did it get there? Early each morning these lockers will be swapped out by self-driving trucks for lockers holding new parcels which have been preloaded the evening before by robots at the local sorting center.

What about larger items? They will still be delivered to our homes by human employees, but they will be using exoskeletons to safely lift heavy weights. They may be assisted by mobile robots carrying several items and following behind the human along their route. If you live in a large apartment building, a small mobile delivery robot may automatically take the elevator to your floor and, once outside your front door, call your mobile phone. You will simply open your door and enter a code into the robot; this allows a compartment to open, and you will be able to access your parcel. If you live in a remote area, a drone may message you from your driveway and require a similar access code procedure. In both cases, you will be able to preplan the delivery time to fit your daily schedule since this single parcel delivery vehicle will be sent only to you.

What if you are not home? Your own personal robot will be able to open the front door to accept the parcel on your behalf. It's more than likely that our homes, cars, and personal robots will all work together in the future, ensuring we always receive our deliveries safely and on time!

LAST-MILE DELIVERY



CONCLUSION AND OUTLOOK

Every day we interact with products that were built by robots and yet we never think about it. These robots impact our world even though they are hidden away in factories that we never see. We are entering a point in time when robots will become more visible and impact our lives more directly: in our stores, in our offices, and in our homes. And as robots improve and our acceptance of them grows, they will also enter the world of logistics.

Interest in the field of robotics is clearly increasing. More funding is pouring into development than ever before from governments, large companies, and venture capitalists. Low-cost sensors and faster computers have made previously impossible challenges more manageable. Engineering students now see true potential for advancement, and are being enticed into this field by exciting jobs in robotics.

Studies show that there will be a labor shortage in many developed countries over the course of the next twenty years. This is problematic for e-commerce, which increases the need for labor in warehouses and greatly adds to the number of parcels flowing to consumer homes.

Finding enough labor for the logistics industry could become extremely difficult or even impossible. In answer to this, managers are learning the advantages of supplementing workers with collaborative robots, effectively allowing people to do more complex and rewarding tasks while at the same time improving overall productivity.

Retailers like Amazon are leading the way, embracing robotics technology by making large investments. Equipment providers see this trend and are designing robots into their logistics systems as the cost of the technology drops and capabilities improve.

With these advances, we are seeing first examples of self-contained mobile picking robots as well as robot forklifts entering distribution centers, and initial trials seem positive. There is still a long way to go before robotics technology is ready and major improvements are still required but many of the pieces are now in place to drive progress.

It seems clear that it is not a matter of "if" but rather "when" robots will be working in our parcel sorting hubs, distribution centers, and delivery vans. The business leaders of the future need to understand this technology and start planning for the day when it provides a viable solution to ever-growing pressures on the supply chain.

The history of robotics includes many stories of hype and disappointment, but if you take a step back you can see steady progress. There is an incredible difference between the robots of the 1960s and those of today. The speed of progress is increasing rapidly with new advancements and breakthroughs happening every day. Our young children can't picture a world without computers and it is likely that their children will feel the same way about robots. The outlook for robotics is very positive and the world of logistics will benefit from the coming advances in robotics technology.

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Tom Bonkenburg is a partner in St. Onge Company, an international supply chain engineering and consulting firm. For the past 18 years Tom has helped top companies design and implement innovative distribution and manufacturing centers. Many of his consulting efforts have focused on developing custom automation and robotics within the distribution and warehousing environments. His past clients have included companies such as Dell Computer, Johnson & Johnson, Wal-Mart, Amazon, ExxonMobil, Baxter Healthcare, Proctor & Gamble, Samsung, Unilever, Adidas, Dow Corning, Kraft Foods, Merck, Urban Outfitters, Lockheed Martin, Stryker, Vistaprint, Becton Dickinson, Boston Scientific, Pepsi, and DHL among others. Tom currently lives in the Netherlands where he leads St. Onge Company's European office.

ABOUT ST. ONGE COMPANY

Since its founding in 1983, St. Onge Company has performed over 3,000 assignments for over 750 clients in more than 50 countries and now has offices in the US, Europe, Middle East, and Asia. As a fully independent consulting company, it provides unbiased supply chain engineering services such as:

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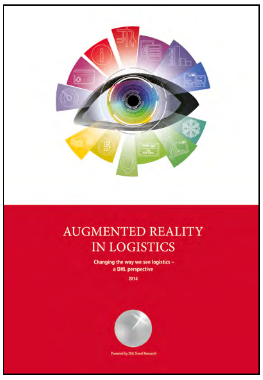

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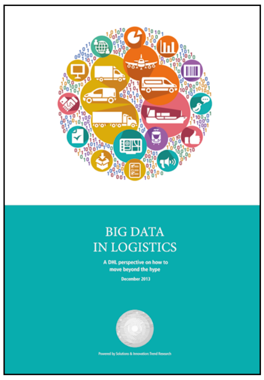

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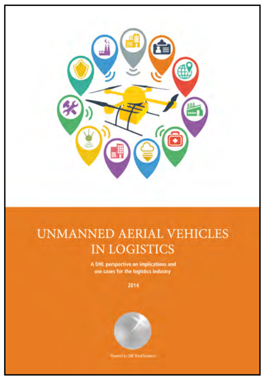

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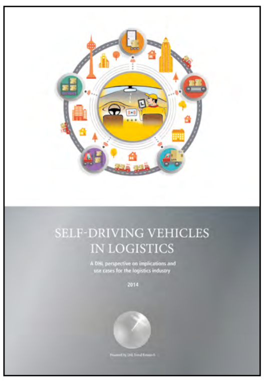

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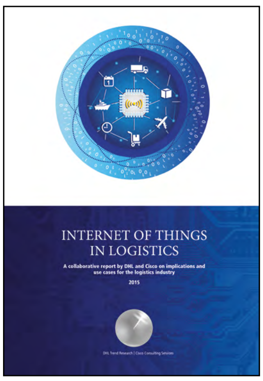

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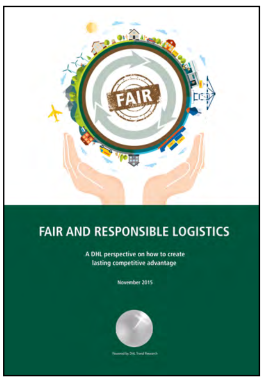

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